Chapter 9: Results and Findings

Results of the Sediment Core Study are divided into the following four sections: (1) Conventional and Descriptive Findings; (2) Radiometric Dating and Sediment Accumulation Rates; (3) Organic Chemical Findings; and (4) Inorganic Chemical Findings.

Interpretation of study results will consist of the following: (a) spatial comparison between the 11 Finger Lakes; (b) temporal comparisons of chemical patterns within 9 of the 11 lakes – unfortunately, sediment chronologies could not be constructed for Cayuga Lake and Hemlock Lake due to inadequate radioisotope profiles; and (c) comparison of sediment core findings to pertinent sediment quality guidance values and discussion of issues of concern.

As was mentioned earlier, the Finger Lakes offer an excellent opportunity for *spatial* comparisons between similar lake systems. The discussion of results will focus on similarities and dissimilarities in chemical patterns between the various lakes. In certain instances, spatial comparisons between adjacent lake systems can provide important clues regarding the origin(s) of chemical constituents. Such a study can help to delineate whether a contaminant problem is originating within a lake watershed (e.g., local hazardous waste site) or from outside the watershed (e.g., atmospheric deposition). For example, if two adjacent lakes indicate a similar chemical profile it is likely that the source is regional, whereas, if only one of the lakes exhibit the pattern the source is more likely local in nature. Other factors that should be considered in such spatial comparisons include physical (morphology, runoff patterns, etc.) chemical (chemical dynamics), and biological (trophic state, food web, etc.) characteristics of the lake systems.

Temporal comparisons of chemical patterns will be based upon chemical chronologies as recorded in the vertical sediment cores. An intact sediment profile can serve a number of purposes in this regard. *First*, the core profile can provide a historical perspective on chemical trends within the lake. Several scenarios are possible, including: (a) chemical levels could decrease with depth (higher concentrations in upper sediments), indicating an increase in chemical inputs to the system over time, or, alternatively, a reduction in sediment loading and static levels of chemical input; (b) chemical levels could increase with depth (higher concentrations in the deeper sediments), indicating a decrease in chemical input to the system over time, or, alternatively, increases in sediment loading and static chemical input; or (c) chemical levels could remain constant with depth, indicating stable chemical input to the system over time. *Second*, while the entire core is of interest with respect to determining chemical trends over time, the upper segments of the core are of particular interest for the following reasons: (a) *chemical availability*: the upper sediment layers are more readily available to resident biota, and available for exchange with the overlying water column; and (b*) current load*: the upper sediment layers provide a picture of current chemical input to the lake and/or watershed. *Third*, sediment core chemical profiles also provide a comparison to chemical uptake information as recorded in biotic indices (e.g., fish flesh date). Thus, the temporal history of chemical inputs as recorded in the sediment profiles can be compared to temporal trends in fish flesh data for those chemicals routinely monitored in sport fish.

The final task to be addressed in the discussion will be to compare observed chemical levels to applicable sediment quality assessment values. At the present time, there are several sets of sediment quality assessment values available for use in freshwater systems. Selection of appropriate assessment values depends upon the intended purpose (e.g., protection of benthic organisms, bioaccumulation and protection of human health, etc.). Once again, greater scrutiny will be placed on upper sediment layers due to their availability to resident biota and possible exchange with overlying water column, as well as their reflection of recent contaminant patterns within the lake and watershed. Specific assessment values will be presented and discussed within the discussion of organic and inorganic findings below.

a. Conventional and Descriptive Findings

The Finger Lakes sediment cores ranged in length from 45 - 77 cm in length (see Table 9.1), indicating good penetration of bottom sediments. There were no instances of core over-penetration (core being pushed beyond the top of the coring devise).

In general, the upper layers of the sediment cores were brown in color and had relatively high water content, while the lower layers of the cores appeared dark gray to black and exhibited lower water content. The color differences could be due to differences in reduction/oxygenation (redox) conditions between the upper and lower sediment layers. At the time of core collection it is likely that the hypolimnion of all of the lakes, with the exception of Otisco Lake, were oxygenated. Thus, pore water within the upper layers of most of the cores would likely be oxygenated, at least to some degree, due to oxygen exchange with the overlying water. In contrast, the lower sediment layers are uniformly deprived of oxygen due to isolation from an available source of oxygen.

Table 9.1: General characteristics of individual cores

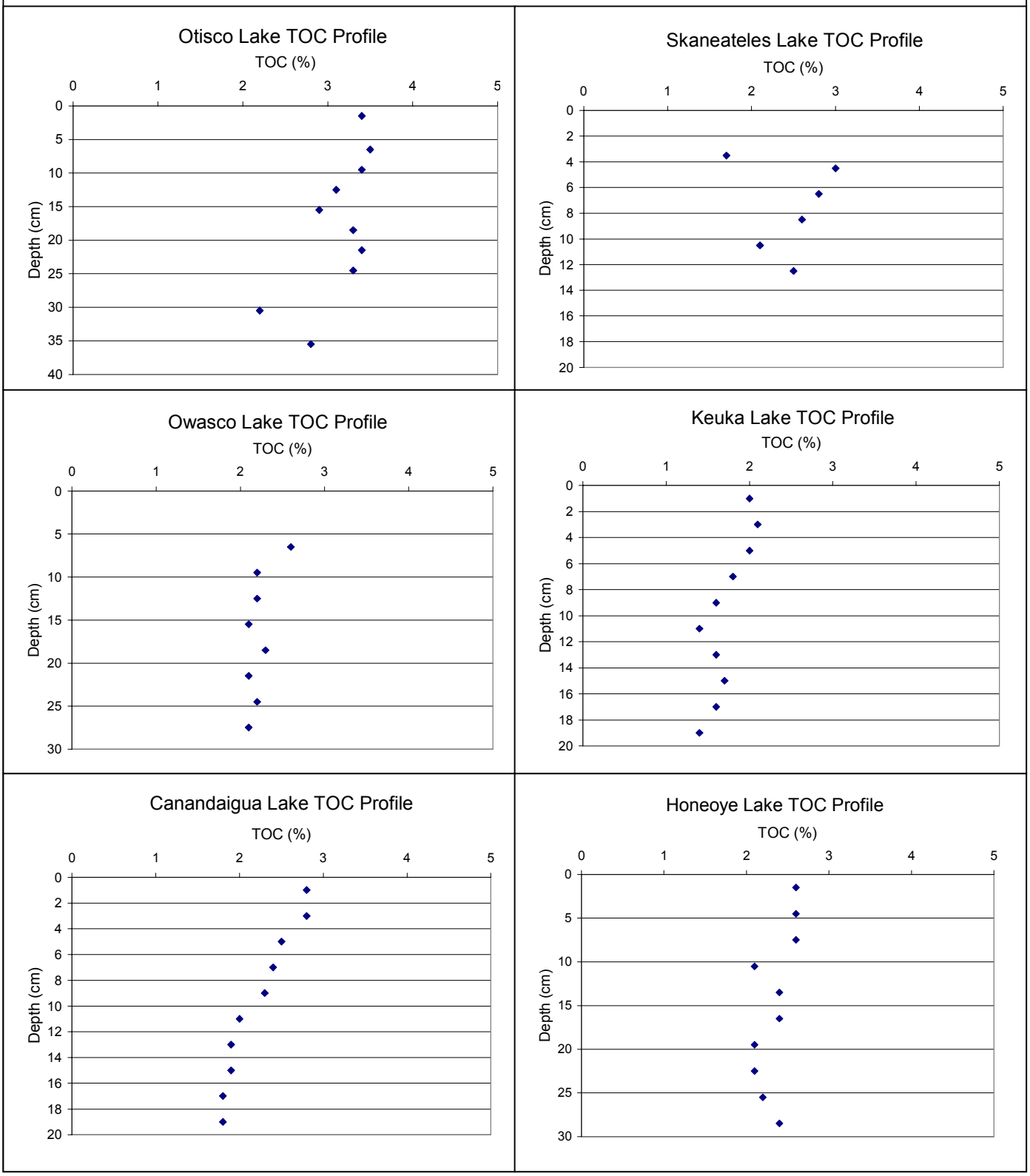
Lake	Length (cm)	Physical Description
Conesus	77	*surface* layers - brown & watery, *deep* layers - black & less water
Hemlock	60	*surface* layers - brown & gray, *deep* layers - black & gray
Canadice	45	*surface* layers - brown, *deep* layers - dark gray to black
Honeoye	62	*surface* layers - brown and gray, *deep* layers - dark gray
Canandaigua	66	*surface* layers - brown, *deep* layers - dark gray to black
Keuka	na	*surface* layers - brown to gray, *deep* layers - dark gray to black
Seneca	69	*surface* layers - brown, *deep* layers - dark gray to black
Cayuga	51	*surface* layers - gray, *deep* layers - dark gray to black
Owasco	61	*surface* layers – brown, *deep* layers - gray
Skaneateles	73	*surface* layers – brown, *deep* layers - gray
Otisco	68	*surface* layers – brown, *deep* layers - gray

Lake sediments are composed of both organic and inorganic materials. The relative percentage of these constituents is indicative of conditions within the lake and it's surrounding watershed. Total organic carbon (TOC) is a common measure used to characterize the benthic sediments of a lake. Organic carbon is composed of plant and animal materials either generated within the lake (autochthonous) or brought to the lake via it's tributary system (allochthonous). In general, sediment TOC levels are expected to parallel the productivity level of the lake – more productive lakes show higher TOC levels while less productive lakes exhibit lower TOC levels.

TOC profiles for 8 of the 11 Finger Lakes are presented in Figures 9.1 and 9.2. As discussed, sediment cores collected from Cayuga and Hemlock Lakes were insufficient for establishing sediment chronologies and are not included. In addition, the Seneca Lake core was not analysed for TOC due to a study oversight.

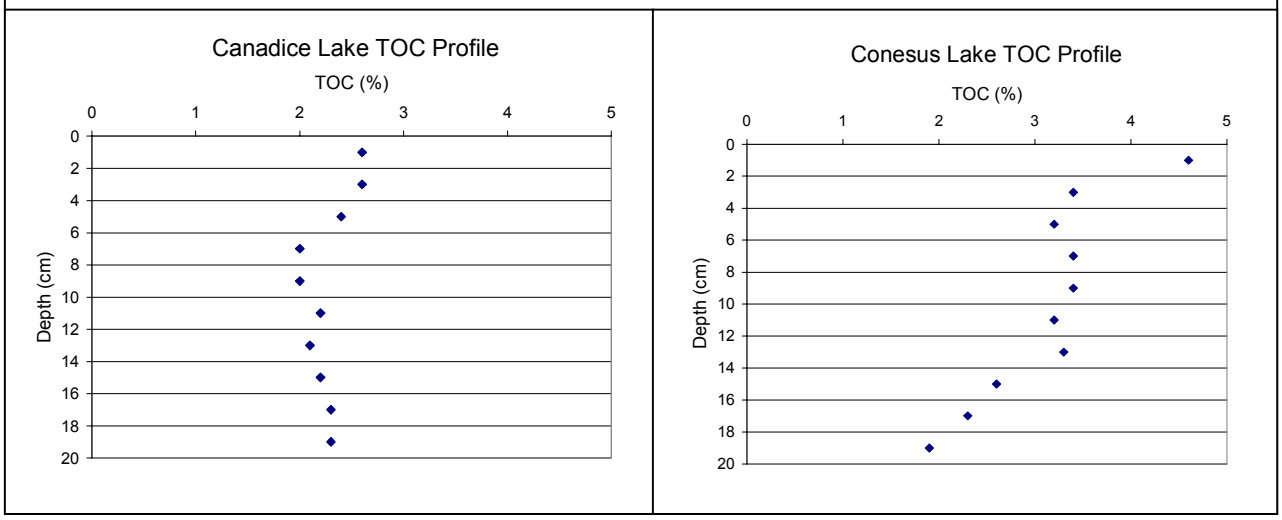
In general, results are reasonably consistent with the premise that benthic TOC levels parallel lake productivity. For example, TOC levels are higher in the Otisco Lake than in Owasco Lake (see Figure 9.1), which is consistent with findings presented above concerning the relative productivity of the two systems. Similarly, TOC levels in upper sediment layers of Conesus Lake are higher than in Canadice Lake (see Figure 9.2), which is again consistent with water quality findings presented above. However, there are some apparent exceptions. For instance, upper layers of Canandaigua and Canadice Lakes show higher TOC levels than would be expected given their productivity levels.

Figure 9.1: Sediment core TOC profiles for 6 of the Finger Lakes (note scale differences)



By contrast, Honeoye Lake, which is relatively productive, showed somewhat lower TOC levels than might have been expected. Findings for Honeoye Lake might be the result of: (a) relatively short retension time of Honeoye Lake, which may limit accumulation of organic matter; and (b) relatively shallow depths and limited stratification – which may keep finer materials in suspension for longer periods.

Figure 9.2: Sediment core TOC profiles for 2 additional Finger Lakes



Temporal trends in TOC levels, as reflected in vertical sediment profiles, can offer some indication of changes in organic loading to a lake over time. However, it is also possible that "apparent" changes are the result of analytical variability. Several of the lake cores indicate an increase in TOC levels beginning in the late 1930s or early 1940s. For example, Canandaigua Lake (Figure 9.1) shows an initial increase in TOC levels beginning at 13.5 cm (circa 1933), and Skaneateles Lake (Figure 9.1) shows an initial increase beginning at 10.5 cm (circa 1944). These observations are consistent with increases in population and development within the watersheds during this time period. In the case of Conesus Lake, TOC levels increase between 19 cm (circa 1950) and 13 cm (circa 1965). However, because we have no record below 19 cm the increase may have begun prior to this point in time. Sediment cores from two of the lakes, Owasco and Keuka Lakes, indicate a more recent increase in TOC levels. The Owasco Lake core shows an increase in TOC at 9 cm (circa 1972), while the Keuka Lake core shows an increase at 11 cm (circa 1971). These more recent TOC increases seem counterintuitive given the observed changes in productivity occuring over the intervening period – stable for Owasco Lake and decreasing for Keuka Lake. TOC trends at the top of the cores suggest fairly stable conditions for most of the lakes. Exceptions include a significant decrease in the case of Skaneateles Lake and a significant increase in the case of Conesus Lake. The direction of these findings are consistent with limnolological findings discussed above in that productrivity levels in Skaneateles Lake have declined markedly over the past several decades while productivity levels within Conesus Lake have increased substantially over the same period. Once again, however, the TOC findings may be analytical anomalies, and would require confirmation from additional cores.

There are no sediment quality assessment values for total organic carbon, however, organic content can play a role in the derivation of organic contaminant assessment values.

b. Radiometric Dating and Sedimentation Accumulation Rates

Radiometric dating is a method of ascribing dates to discreet segments of a vertical sediment core. The process involves analyzing vertical core segments for specific radioisotopes.

Two of the more common radioisotopes used for dating of relatively recent sediments (100 years of age, or less) are cesium 137 (^{137}Cs) and lead 210 (^{210}Pb). The two isotopes are often used in concert for sediment dating purposes, with date estimates of one isotope acting as confirmation of dates established using the other isotope. For this study, cesium 137 (^{137}Cs) is used as the primary isotope, and lead 210(^{210}Pb) is used as the secondary, or confirmatory radioisotope – see further discussion in box below.

Vertical profiles of ^{137}Cs for each of the Finger Lakes sediment cores are presented in Figure 9.3 (eastern 6 lakes) and Figure 9.4 (western 5 lakes). The ^{137}Cs profiles from all but 2 of the lakes (Cayuga and Hemlock Lakes) were deemed acceptable for dating purposes in that they exhibited ^{137}Cs profiles consistent with known fallout trends resulting from nuclear weapons testing.

For example, the Skaneateles Lake plot (Figure 9.3) shows an increase in ^{137}Cs levels from the surface of the core down to approximately 7 cm (cesium peak). This is followed by a decrease in ^{137}Cs levels thereafter down to virtually zero at a sediment depth of approximately 12.5 cm (cesium horizon). This indicates that Skaneateles Lake sediments located at a depth of 7 cm were deposited at or around the peak in above-ground nuclear weapons testing in 1963, and that sediments at a depth of 12.5 cm were deposited at or around the onset of large-scale nuclear weapons testing in the early 1950s. Similar trends of increasing ^{137}Cs levels to a given depth, followed by decreasing levels thereafter were observed for 7 of the other Finger Lakes (Conesus, Canadice, Canandaigua, Keuka, Seneca, Owasco, and Otisco Lakes), and an acceptable ^{137}Cs horizon was available for an additional lake (Honeoye Lake). Table 9.2 provides a summary of ^{137}Cs markers for the Finger Lakes.

Table 9.2: Depth of ^{137}Cs markers

	^{137}Cesium	
Lake	Peak (cm)	Horizon (cm)
Conesus	13	19.5
Hemlock	na	na
Canadice	5	9
Honeoye	na	19.5
Canandaigua	7	13
Keuka	13	21
Seneca	7	15
Cayuga	na	na
Owasco	12.5	24.5
Skaneateles	6.5	12.5
Otisco	24.5	na

^{137}Cs profiles for Cayuga Lake and Hemlock Lake sediment cores were not sufficient for determination of time chronologies.

In contrast to the "well behaved" cores discussed above, the ^{137}Cs trends in Cayuga Lake (Figure 9.3) and Hemlock Lake (Figure 9.4) do not show a pattern of ^{137}Cs deposition consistent with known fallout patterns. It is possible, that the ^{137}Cs profile for Cayuga Lake is intact but incomplete (^{137}Cs peak is present, but horizon is not present). However, if this is so, than the sedimentation rate within Cayuga Lake is extremely high (approaching 1 cm/year). Fortunately, in the case of Cayuga Lake, previous coring efforts conducted by the United State Geological Society (Yager, 1999) provided acceptable estimates of sedimentation rates and sediment chronology. Unfortunately, no alternative source of data is available for Hemlock Lake.

In summary, reasonable temporal chronologies and sediment accumulation rates (SAR) are available for 10 of the 11 Finger Lakes, and acceptable sediment chronologies are available for 9 of the 11 lakes.

Radiometric Dating (^{137}Cs and ^{210}Pb)

Rainfall and erosion activities within a lake watershed result in the transport of sediments and associated chemicals to a lake. These suspended sediments, or a portion thereof, eventually "rain" down from the water column and reach the lake bottom. If these sediments come to rest in so-called depositional areas of a lake they record the temporal history of chemical inputs to the lake. By extracting and vertically segmenting these sediments (sediment cores) one can document historical chemical patterns within a lake. However, in order to ascribe specific dates to individual core segments one must identify temporal markers that can be used to date the given segment. Temporal markers can include either chemical (e.g., radioisotopes) or biological (e.g., pollen) constituents of the sediments. In this study we used two radioisotopes (^{137}Cs and ^{210}Pb) to date sediment core segments. The methods used to derive sediment dates vary for the two radioisotope markers. Dates associated with ^{137}Cs are premised on temporal markers associated specific historical events, while dates derived from ^{210}Pb are based upon the natural decay of the isotope.

^{137}Cs is a byproduct of nuclear weapons testing. Atmospheric testing of nuclear weapons began in the 1940s, accelerated through the 1950s and early 1960s, and declined thereafter (replaced by below-ground weapons testing). This historical chronology provides two distinct temporal markers associated with ^{137}Cs deposition as follows: (1) ^{137}Cs *horizon*: which refers to the first appearance of ^{137}Cs in the environment – generally considered to represent the early 1950s (e.g., 1952) – resulting from large-scale nuclear weapons testing; and (2) ^{137}Cs *peak*: which refers to the period of maximum above-ground nuclear testing and subsequent ^{137}Cs fallout – generally considered to have occurred in the early 1960s (e.g., 1963) – resulting from "unloading" of weapons stockpiles in advance of a world-wide atmospheric test ban treaty in 1964. Figures 9.5 and 9.6 depict world-wide above-ground nuclear weapons testing and ^{137}Cs fallout in Finland, respectively.

^{210}Pb is a naturally occurring uranium (U) isotope. Major intermediate isotopes in the decay of 238Ur, and their approximate half-lives (years), are as follows:

^{238}U (4.5×10^{9}) → ^{234}U (2.5×10^{5}) → ^{230}Th (7.5×10^{4}) → ^{226}Ra (1.6×10^{3}) → **^{210}Pb** (22.3) → ^{206}Pb (stable)

The half-life of ^{210}Pb (22.26 years) provides a reference by which to estimate sediment dates within lake sediments. The process involves the following steps: (1) plot $^{210}Pb_{ex}$ concentrations within the vertical sediment core against sediment depth, (2) determine the depth of sediment accumulation which results in a halving of excess ^{210}Pb levels; and (3) divide this value by the half-life of ^{210}Pb.

Figure 9.5: Above ground nuclear weapons testing estimated yield

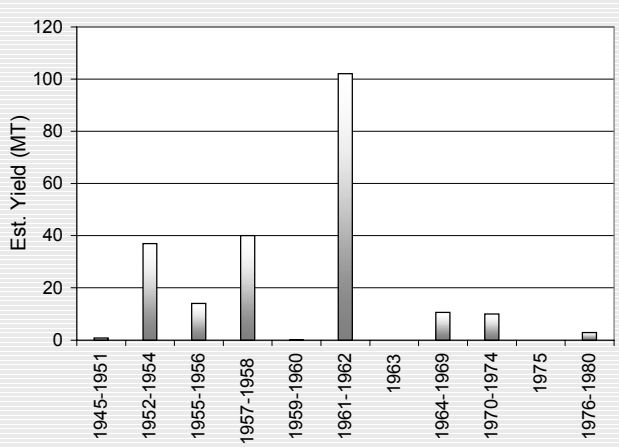


Figure 9.6: Record 137Cs fallout – Finland

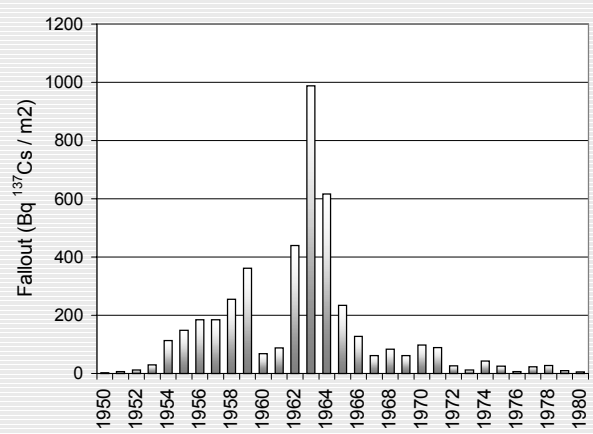


Figure 9.3: Sediment core ^{137}Cesium profiles for 6 eastern lakes (note scale differences)

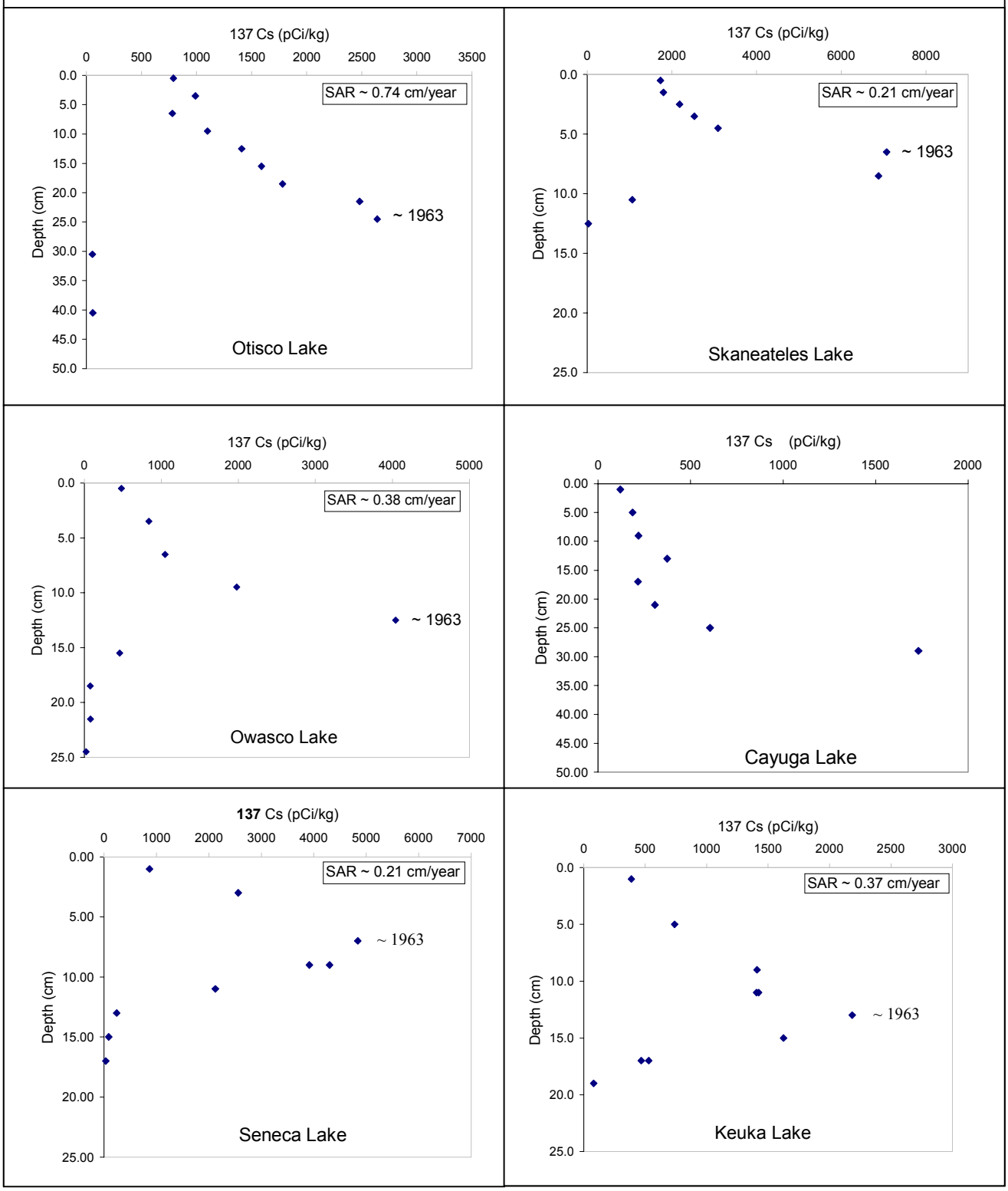
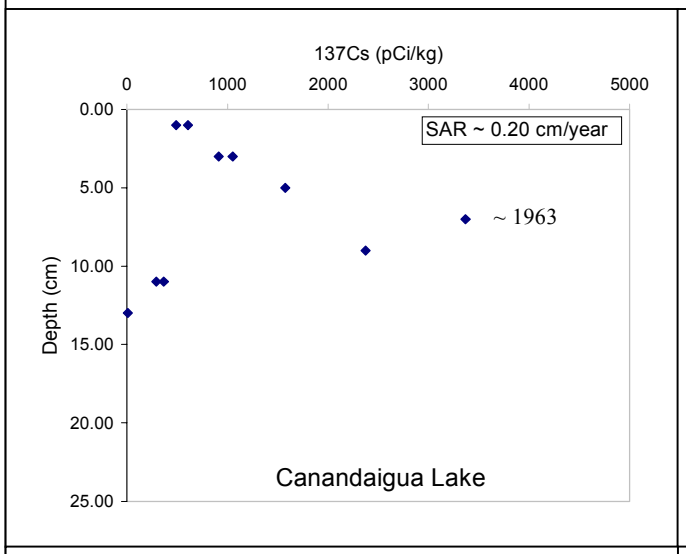
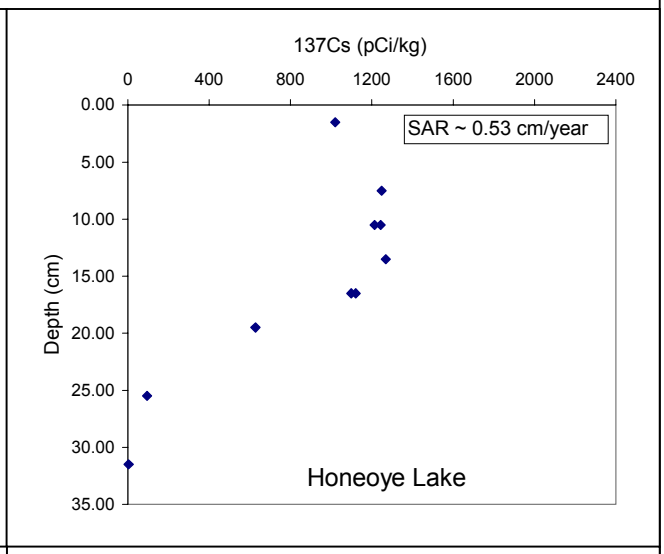
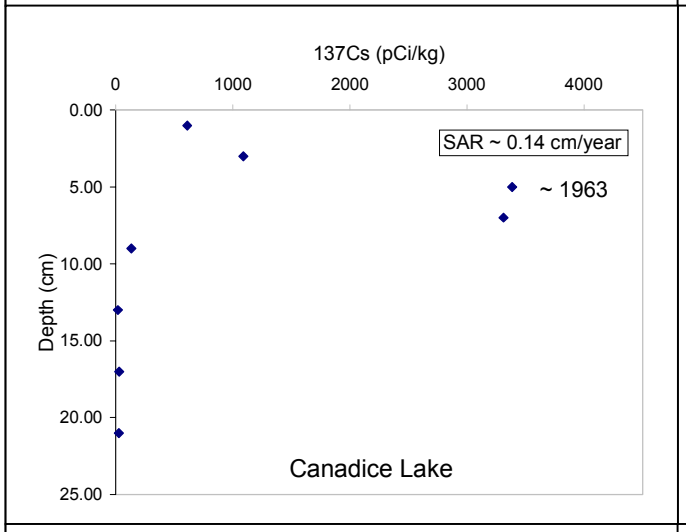
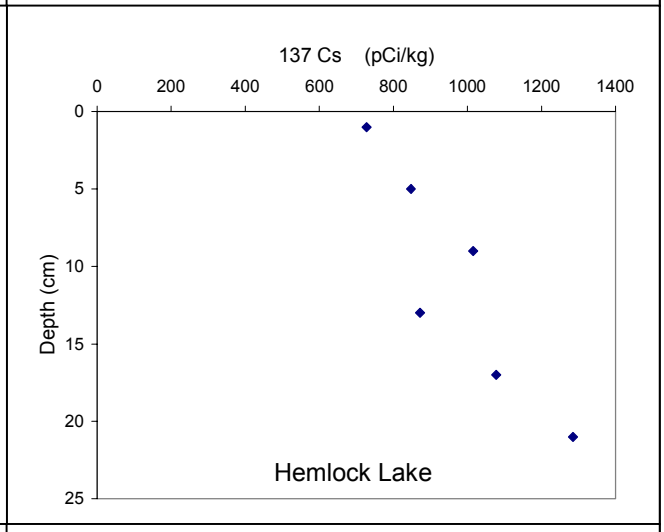


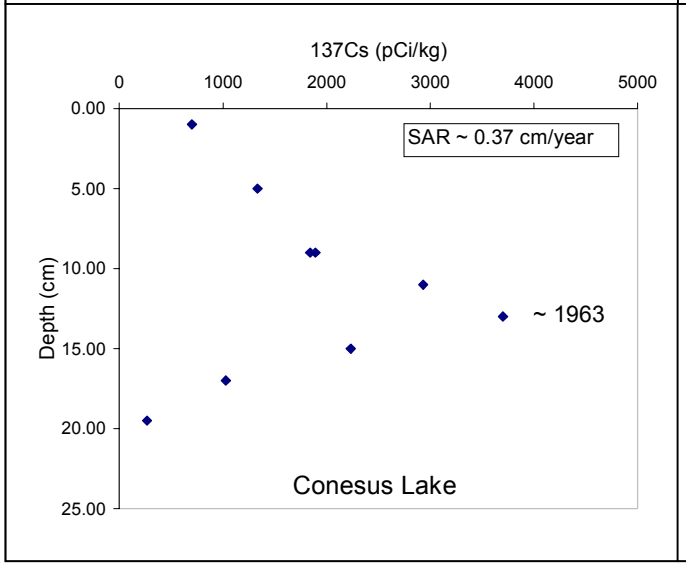
Figure 9.4: Sediment core ^{137}Cesium profiles for 5 western lakes (note scale differences)











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Sediment accumulation rates (SARs) for each of the Finger Lakes, as derived from both ^{137}Cs profiles (both peak and horizon) and ^{210}Pb profiles, are shown in Table 9.3. It is important to keep in mind that the reported SARs are for a single location within each lake, and that some longitudinal variation would be expected – particularly, for the larger (longer) lakes. The SAR shown for Cayuga Lake is based on an average of 6 cores collected by the USGS (Yager, 2001) during the early to mid 1990s. SARs, based upon ^{137}Cs, range from 0.17 cm/year for Canadice Lake to 0.74 cm/year for Otisco Lake. The rates derived by both ^{137}Cs markers (peak and horizon) and ^{210}Pb are reasonably consistent for each lake. The only major exception to this finding was for Otisco Lake, which shows a higher SAR based upon ^{137}Cs than that based on ^{210}Pb. The reason for this disparity is not clear.

Table 9.3: Sediment accumulation rates (cm/year)

Lake	^{137}Cesium		^{210}Lead	Comments
	Peak	Horizon		
Conesus	0.37	0.42	0.41	
Hemlock	na	na	na	No useable data
Canadice	0.17	0.23	0.23	
Honeoye	na	0.53	na	No discernible ^{137}Cs peak
Canandaigua	0.20	0.25	0.3	
Keuka	0.37	0.40	0.45	
Seneca	0.23	0.33	0.32	
Cayuga	0.42	na	na	Based on USGS data (Yager, unpublished)
Owasco	0.38	0.5	0.45	
Skaneateles	0.21	0.28	0.26	
Otisco	0.74	na	0.54	^{137}Cs rate ~ 40 percent higher than ^{210}Pb rate

The sediments within a lake can originate in two principle ways: (1) externally: sediments can be eroded from the lake catchment and delivered via the tributary system to the lake – this typically includes both organic and inorganic sediments; and/or (2) internally: sediments can originate internally via the growth and senescence of plant (phytoplankton and macrophytes) and animal communities – these are strictly organic sediments.

If the sediments of a lake are primarily of internal origin (algal growth and senescence) then the SAR is likely to reflect the long-term trophic state of the lake. The SARs derived for the Finger Lakes are reasonably consistent with trophic state findings presented earlier in that the eutrophic Finger Lakes (e.g., Otisco and Honeoye Lakes) generally exhibit higher SARs than do the oligotrophic Finger Lakes (e.g., Skaneateles and Canandaigua Lakes). These findings are consistent with expectations, in that higher trophic status reflects greater productivity which results in greater particulate material available for deposition. There are, however, some apparent anomalies to this general finding.

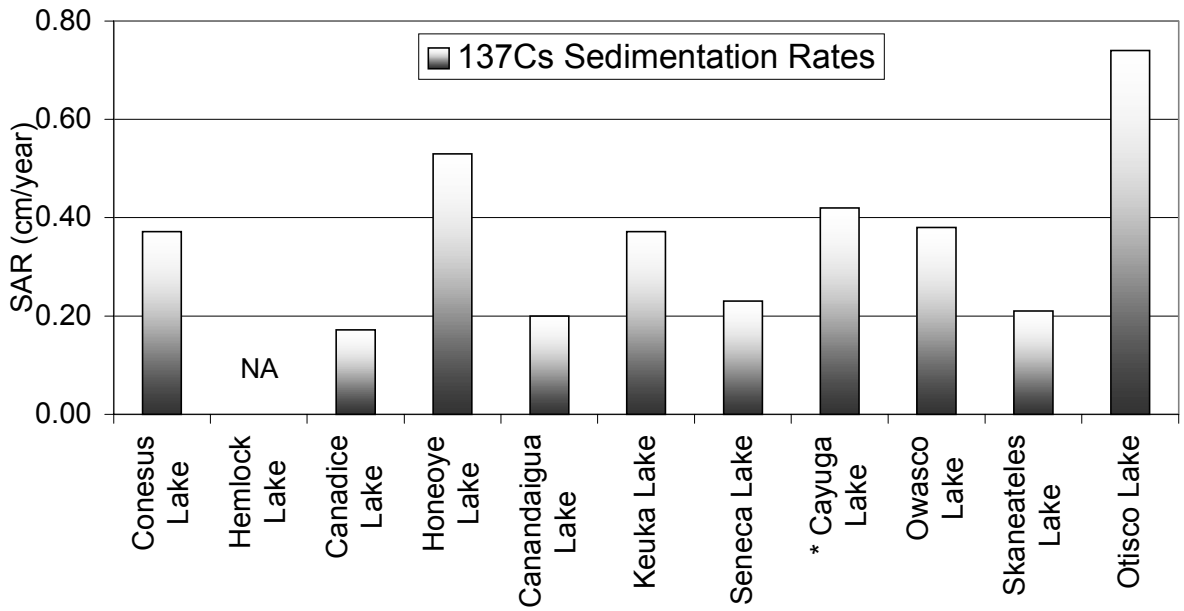
For example, the SAR for Cayuga Lake is slightly greater than that for Conesus Lake, whereas, the current trophic state of Conesus Lake is greater than that of Cayuga Lake. There are several possible explanations for this apparent disparity. First, SARs, by definition, represent an integration of conditions over time, whereas, trophic status is a snapshot in time. You may recall from the earlier discussion of trophic state that the trophic status of Cayuga Lake (main lake) has dropped significantly since the 1970s as reflected in total phosphorus and chlorophyll a levels (see Tables 5.3 and 5.4). Thus, the SAR for Cayuga Lake, or any waterbody, is indicative of long-term conditions, and may be somewhat inconsistent with conditions at any one instant in time. Second, the Cayuga Lake cores used for derivation of SAR were all collected in the southern third of the lake and may be somewhat biased due to conditions in the south end of the lake (e.g., tributary inflow, sewage discharge, etc.) which is considerably more productive than the deeper basin of the lake.

Figure 9.7 provides a graphical comparison of SARs within the Finger Lakes based upon ^{137}Cs findings. The rates presented are best estimates of sediment accumulation rates based on radiometric measures and selected chemical markers.

The SARs presented for Conesus, Canadice, Keuka, Owasco, Skaneateles, and Otisco Lakes are based upon the ^{137}Cs peak observed in each of the cores. The rates presented for both Seneca Lake and Canandaigua Lake are based upon the ^{137}Cs horizon observed in the respective cores. The reason for use of this modified approach for these particular cores stems from observations of specific chemical markers (see discussion of DDT and metabolites below). As with ^{137}Cs, these organic substances have a fairly well defined temporal history that can be used to "fine-tune" the radiometrically derived chronology. Thus, when this sort of additional information is available, one generally takes a "weight of the evidence" approach in interpreting sediment chronology and assessing accumulation rates.

Finally, as discussed earlier, the SAR reported for Cayuga Lake represents an average SAR based upon the ^{137}Cs peaks observed in 6 cores taken by USGS in the early 1990s (Yager, 2001).

Figure 9.7: Estimate of sediment accumulation rates



c. Organic Chemical Findings

The suite of organic chemicals analyzed during this investigation are shown in Table 8.2. Of the approximately 25 substances investigated, only a few were present at detectable levels within the Finger Lakes sediment cores. The substances detected most often include: (1) dichlorodiphenyl-trichloroethane (DDT) and related compounds dichlorodiphenyl-dichloroethylene (DDE) and dichlorodiphenyl-dichloroethane (DDD); and (2) Polychlorinated biphenyl's (PCBs). Both groups of substances are termed organochlorines, and have largely been banned for use in the United States. However, these substances continue to cycle through many aquatic environments due to their persistence and ability to bioaccumulate. As discussed earlier, these are the chemicals responsible for the current fish consumption advisories in Canadice Lake (PCBs), Canandaigua Lake (PCBs), and Keuka Lake (DDT).

As alluded to earlier, several sets of sediment quality assessment values are available for use in freshwater systems. Representative values for organic chemicals at issue within the Finger Lakes are presented in Table 9.4. The values are taken from a compilation of sediment criteria compiled by Smith et al. (1996). The threshold effect level (TEL) implies occasional adverse effects on resident biota, whereas, the probable effect level (PEL) implies frequent adverse effects on biota.

Table 9.4: Sediment guidance criteria for selected organic chemicals

Substance	TEL (ppb)	PEL (ppb)
Total DDT	7	4,450
Total PCBs	34.1	277

TEL: threshold effect level (Smith, et al., 1996)
PEL: probable effect level (Smith, et al., 1996)

DDT and Related Compounds

DDT is a synthetic (human-made) insecticide composed of carbon, hydrogen and chlorine atoms (see further discussion in box below). DDT gained widespread use in the 1940s following World War II. Once heralded as the "savior of mankind" due to its ability to control the insect vectors responsible for the spread of many human diseases, DDT began to fall out of favor in the 1960s as concerns over its efficacy and safety (environmental and human health) came into question. DDT was banned for use in the United States in 1972, however, the compound is still in use in several developing countries (e.g., Mexico).

Findings for DDT and its metabolites are only available for 7 of the 8 western Finger Lakes, as cores from the 3 eastern lakes and Honeoye Lake were not analyzed for these compounds.

Spatial comparisons of the lakes indicate that DDT was detectable in certain segments of all 7 of the lakes evaluated, however, levels varied significantly between lakes (see Table 9.5). From a historical context, Keuka Lake had the highest ΣDDT (DDT + DDD + DDE) level, which occurred in the 12-14 cm sediment increment. The fact that Keuka Lake exhibited the highest DDT levels is not surprising given the standing fish consumption advisory on Keuka Lake. Two of the other Finger Lakes, Seneca and Canandaigua Lakes, also showed relatively high historical ΣDDT levels – note the peak levels of 153 ppb and 219 ppb, respectively. With respect to DDT levels in surface sediments, Keuka Lake again shows the highest ΣDDT levels (72 ppb), followed by Seneca Lake (40 ppb) and Conesus Lake (30 ppb). As noted earlier, it is not possible to discern temporal trends in the Cayuga and Hemlock cores do to apparent mixing within the core sediments, however, both cores exhibited detectable ΣDDT levels – somewhat higher in Hemlock Lake than in Cayuga Lake. It is important to view these findings as composite or aggregate values.

DDT and Related Compounds

DDT was initially synthesized by a German graduate student in 1874. However, more than half a century would pass before the commercial utility of the compound became known. In 1939, a Swiss entomologist named Dr. Paul Muller found that DDT was a potent insecticide. The importance of Muller's discovery is underscored by the fact that he was awarded the Nobel Prize in Medicine in 1948 due to the importance of DDT in the control of several human diseases. Following its initial use to control insect vectors of human diseases (e.g., malaria, typhus, yellow fever, etc.), DDT was eventually used to control a broad array of insect pests (both agricultural and non-agricultural pests). The list of target insects included codling moths (important pest in fruit orchards), spruce bud worms (important pest in silvaculture), and elm bark beetles (vector for Dutch Elm disease).

While of significant importance in the control of both human disease vectors and insect pests in general, environmental and human health concerns relating to DDT began to arise in the late 1940s and 1950s. These concerns would reach a worldwide audience with the release of Silent Spring (Carson, 1962). Use of DDT in the United States peaked in the early 1960s, and declined thereafter for the following reasons: (1) development of resistance in certain target species; (2) concerns regarding its effects on the environment and human health; and (3) introduction of alternative insecticides. DDT use was banned in the United Sates in 1972, however, several countries continue to use the compound.

DDT consists of two phenyl (six carbon hexagon) rings - thus diphenyl - with 2 chlorines attached to the ring structures and 3 additional chlorine molecules attached to the central carbon molecule. The chemical structure of DDT is shown in Figure 9.8. The two principal metabolites (or breakdown products) of DDT are DDE and DDD (Figures 9.9 and 9.10, respectively). DDD was actually marketed separately as an insecticide, while DDE has never been marketed commercially and is only found as a by-product of DDT breakdown. While DDT and its metabolites can be degraded within the environment, the rate of degradation is quite slow.

As with other organochlorine compounds, DDT has a strong affinity for organic material and will accumulate within lipid (fat) deposits of living organisms. This propensity for DDT and related compounds to concentrate within biota is termed bioaccumulation. This process, coupled with the compound's persistence within the environment, has led to significant environmental problems. The most widely heralded being the precipitous decline in predatory bird populations (e.g., Bald eagles) in North America due to eggshell thinning and embryo deaths.

DDT and its metabolites have been shown to cause chronic adverse health effects on the liver, kidneys, nervous system, immune system, and reproductive system in experimental animals. In addition, the USEPA considers these compounds to be suspected human carcinogens. Fish consumption advisories (e.g., Keuka Lake) are based upon a United States Food and Drug Administration (FDA) limit of 5 ppm.

Figure 9.8: Structure of DDT
Chlorine molecule (green)

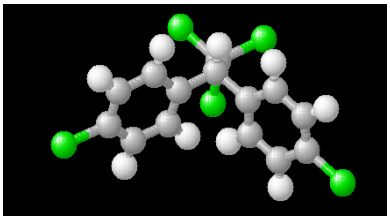


Figure 9.9: Structure of DDE
Carbon molecule (gray)

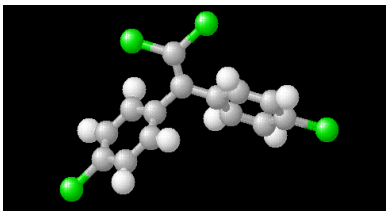
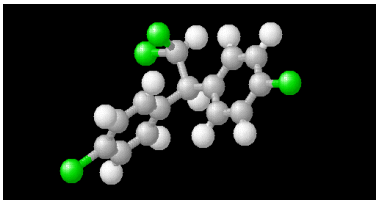


Figure 9.10: Structure of DDD
Hydrogen molecule (white)

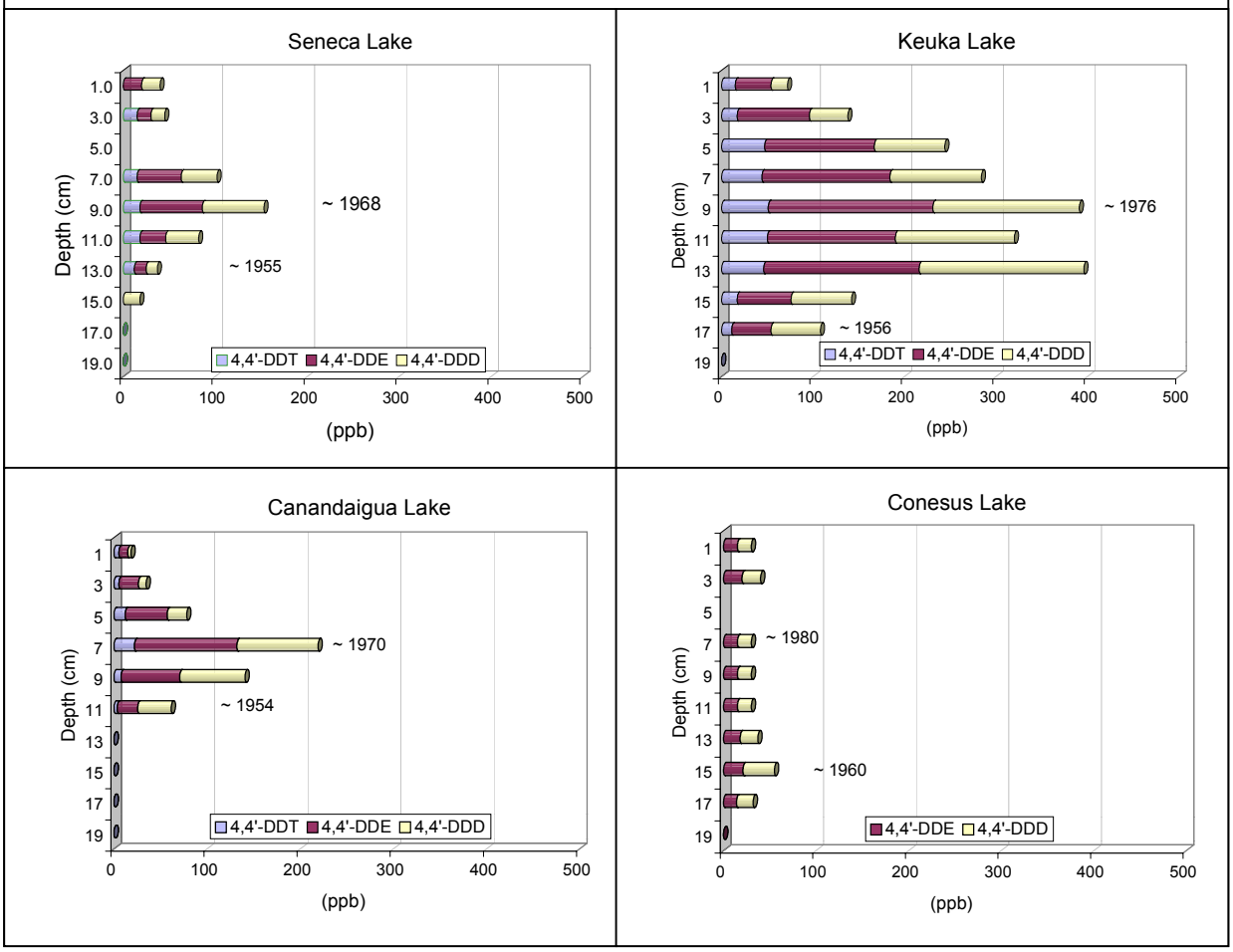


Figures from: http:www.atsdr.cdc.gov

Table 9.5: Finger Lakes sediment cores Σ DDT summary			
Lake	*Peak Σ DDT (ppb)*	*Surface Σ DDT (ppb)*	*Comments*
Cayuga	30 – depth na	na	no temporal significance
Seneca	153 @ 8-10 cm	40	second highest surface level
Keuka	396 @ 12-14 cm	72	DDT-based fish consumption advisory
Canandaigua	219 @ 6-8 cm	18.2	Second highest peak level
Honeoye	na	na	
Canadice	65 @ 6-8 cm	5.6	
Hemlock	54 – depth na	na	no temporal significance
Conesus	55 @ 14-16 cm	30	
TEL: 7 ppb PEL: 4,450 ppb			

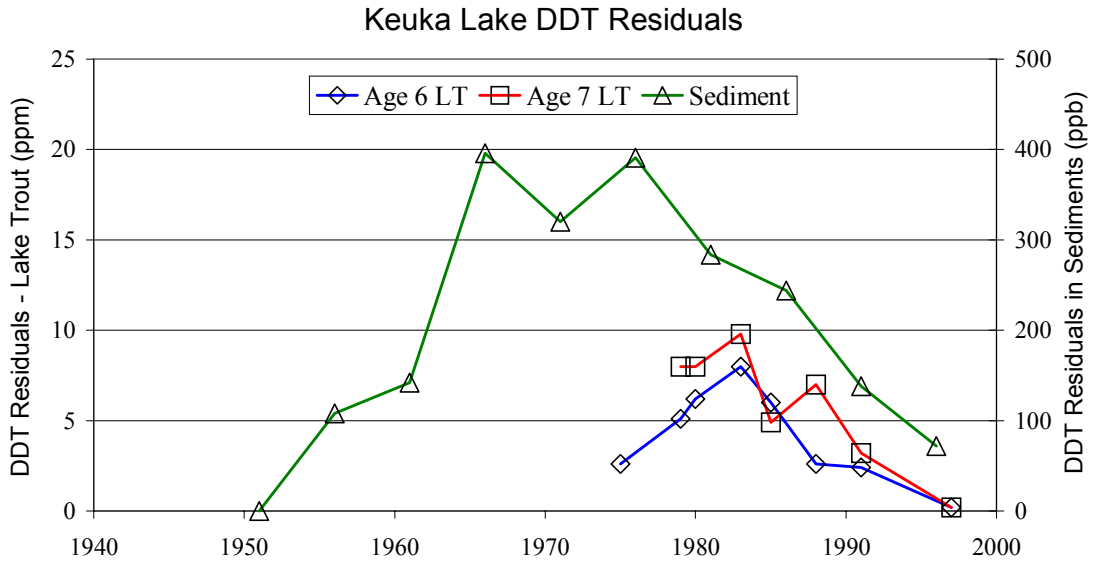
In general, DDT levels within the western 7 lakes are declining in both the sediments and biota. Temporal profiles of DDT, DDE, and DDD from sediment cores taken in 4 of the Finger Lakes are presented in Figure 9.11. Trends indicate that DDT and its metabolites have been declining over the past several decades within the study lakes. For example, ΣDDT levels in Keuka Lake sediments have declined by more than 5 fold from nearly 400 ppb in the mid 1970s to approximately 70 ppb in the mid 1990s. Steep declines are also apparent in both Seneca Lake (~ 4 fold decline over 30 years) and Canandaigua Lake (~ 12 fold decline over 30 years). The temporal pattern observed in Conesus Lake is somewhat different than the other three lakes. For instance, Conesus Lake does not show the marked decline in ΣDDT levels exhibited by the other 3 lakes. On the other hand, historical ΣDDT levels in the sediments of Conesus Lake are considerably less than in the other 3 lakes. Another temporal difference relates to the date of the observed peak in ΣDDT levels. For the 3 larger lakes, the peak in ΣDDT levels coincides with the late 1960s and early 1970s, whereas the peak for Conesus Lake is somewhat earlier (~ 1960). One additional difference relates to the relative proportions of DDT and it principal metabolites DDE and DDD. The 3 larger lakes exhibited detectable levels of the parent compound in most of the core segments, while Conesus Lake only contained detectable levels of the metabolites. While this pattern difference might be explained by the relatively low concentrations of ΣDDT found in Conesus Lake, an alternative explanation is that it might reflect the relative age of the DDT signal. A common approach used to estimate the "age" of a DDT source is to compare the relative ratios of the parent compound (DDT) to its metabolites (DDE and DDD). Obviously, the absence of a detectable DDT signal in the Conesus Lake core, would indicate an enrichment of the metabolites relative to the parent compound. Thus, it is conceivable that the original source of DDT contamination within Conesus Lake is somewhat older than in the other lakes. This is consistent with the observation that the peak in ΣDDT within Conesus Lake is approximately 10 years earlier than in the other 3 lakes. However, this raises the question of why the levels of ΣDDT in Conesus Lake sediments have not declined significantly within recent years. Plausible explanations for the observed plateau in ΣDDT levels within Conesus Lake include: (1) possible use of DDD within the watershed - DDD was used independently as an insecticide in the US for several years following the ban on DDT; (2) more effective ecosystem recycling of DDT and it's metabolites – Conesus Lake is substantially shallower than the other three Finger Lakes and may be more susceptible to resuspension events; (3) ongoing release of metabolites within the watershed.

Figure 9.11: Sediment core profiles of DDT, DDE, and DDD for selected Finger Lakes



Fish flesh analyses have been conducted on sport fish taken from the Finger Lakes for several decades. This data is the basis for the fish consumption advisories currently in place for several of the Finger Lakes and other water bodies within New York State. As with the sediment profiles, DDT trends in fish within the Finger Lakes have also been decreasing (see Figure 9.12). For example, lake trout (ages 6 & 8 years) from Keuka Lake have shown a 30-40 fold reduction in ΣDDT level over the past decade and a half. The US Food and Drug action level for DDT in fish flesh is 5 ppm, and the most recent data indicate that Lake trout from all age ranges are below this level. It is also interesting to compare the pattern of reduction between the sediments and the fish. There is a noticeable delay between the peak in sediment concentrations and the peak in fish concentrations (see Figure 9.12). This is consistent with expectations in that fish accumulate these compounds over time and reflect environmental conditions in aggregate, while specific sediment core segments represent conditions at a discreet instance in time. Fish flesh data for the other Finger Lakes are less extensive than for Keuka Lake, however, the general trend is toward decreasing levels of DDT contamination.

Figure 9.12: Comparison of ΣDDT levels in fish flesh and sediments from Keuka Lake.



Beginning in 1996, the NYSDEC Division of Fish, Wildlife and Marine Resources initiated an investigation within the Keuka Lake watershed in an effort to track down the source(s) of DDT (and related compounds) to the lake (Spodaryk, et al., 2000). The investigation involved the deployment of passive in-situ chemical extraction samplers (PISCES) on various tributaries within the watershed. Findings indicated elevated ΣDDT levels in Tributary 64, which enters Keuka Lake near Bluff Point. The probable source of the DDT to Tributary 64 was determined to be an old disposal area just upstream from Central Avenue in Keuka Park. Track down efforts were concluded in 1999, due to the continuing decline in ΣDDT levels recorded in Keuka Lake biota.

Sediment quality assessment values for ΣDDT are listed in Table 9.4. Once again, the primary focus of this discussion will be on surficial sediments due to biological availability considerations. Surficial sediment ΣDDT levels in 4 of the 5 Finger Lakes with available DDT data are above the TEL guidance level of 7 ppb. Canadice Lake was the only one of these lakes that had surficial sediment levels below the TEL. It is not possible to determine the surficial ΣDDT levels in Cayuga and Hemlock Lakes – due to apparent disturbance of these sediments. None of the Finger Lakes sediment cores showed ΣDDT levels above the PEL of 4,450 ppb. It should be noted, however, that the PEL was not even exceeded within the Keuka Lake sediment core (at any depth), which has had a fish consumption advisory for a number of years due to DDT levels within certain fish species. Thus, failure to exceed the existing PEL should not be interpreted as precluding fish tainting. Peak historical ΣDDT levels observed in Keuka, Canandaigua, and Seneca Lakes warrant consideration should dredging activities within near shore areas be considered in the future, or if unusually large hydrologic events occur. Such activities could conceivably disturb and remobilize these DDT-laden sediments.

PCBs – Arochlors and Congeners

As with DDT and its metabolites, PCBs are a class of man-made organic compounds composed of carbon, hydrogen and chlorine atoms (see further discussion in box below). Originally introduced for industrial use in 1929, US production of PCBs reached a peak of 85 million pounds in 1970 (HHS, 1993). PCBs were used for a wide variety of industrial applications ranging from electrical transformers to carbon-less copy paper. The use of PCBs within the United States has been greatly curtailed over the past several decades.

PCBs tend to bioaccumulate due to their environmental persistence and lipophilic/hydrophobic nature. The property of persistence allows PCBs to circulate for extended periods within the environment, while the properties of lipophilicity and hydrophobicity facilitate the molecule's association with organic and particulate matter, respectively.

PCB analyses can involve quantification of either Aroclors (commercial product composed of specific congeners) or individual congeners. Figure 9.13 provides a visual illustration of a number of the major Aroclor formulations. Given the analytical costs associated with the two methods (congener method is significantly more expensive than Aroclor method), most of the analyses from this study focused upon Aroclors. Aroclor analyses were conducted on approximately 8-10 core segments from each sediment core from the western eight lakes, while congener analyses were run on only one segment from each of the Finger Lakes cores.

As it turns out, most of the Aroclor analyses conducted during this investigation were below detection. Only one sediment core segment, Canadice Lake (2-4 cm), showed reportable Aroclor levels (Aroclor 1260 at 67 ppb). On the other hand, all sediment cores for which congener analyses were conducted showed reportable levels of congeners. Total congener values for these sediment cores are included in Table 9.6. The table includes both actual totals and adjusted totals (total congeners minus p,p'DDE + IUPAC-85, which co-elute on the chromatogram). As can be seen in Table 9.6, this adjustment is important for several of the Finger Lakes (Keuka and Seneca Lakes). This is consistent with findings discussed above concerning past DDT contamination in these lakes. PCB levels were highest in Conesus, Canadice, Seneca, and Owasco Lakes. Keuka, Otisco, and Skaneateles Lakes fall into an intermediate category, and Honeoye Lake showed the lowest PCB levels. It is important to note that the reference timeframes differ among the lakes, ranging from the early 1970s to the early 1990s. Total congener levels found in the Cayuga Lake core segment were also quite low, however, the Cayuga core segment must be viewed as a composite, rather than a discrete moment in time, due to the failure to establish an intact cesium profile.

Table 9.6: Total congeners for Finger Lakes core segments

Lake	*Approximate Date*	*Σ Congeners (ppb)*	**Adjusted Congeners (ppb)*
Conesus Lake	1985	490	481
Hemlock Lake	na**	67	62
Canadice Lake	1973	352	342
Honeoye Lake	1990	69	65
Canandaigua Lake	na	na	na
Keuka Lake	1986	449	289
Seneca Lake	1978	466	408
Cayuga Lake	na**	76	74
Owasco Lake	1987	374	370
Skaneateles Lake	1984	286	278
Otisco Lake	1991	245	243

*: Total congeners minus IUPAC-85 and DDE
**: not appropriate due to failure of radiometric dating

PCBs

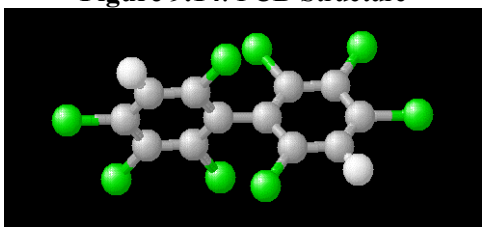
PCBs (see Figure 9.14) were originally synthesized in the late 1800s, but were not used commercially until the late 1920s. The Monsanto Company was the sole manufacturer of PCBs in the US (CEC, 1996). From an industrial perspective, PCBs offer a number of attractive properties. The properties of greatest value to industry include low conductivity (good insulator), flame retardant, and chemical stability. PCBs were used in products ranging from electrical transformers to carbon-less copy paper. The total quantity of PCBs produced in the US between 1929 and 1977 is estimated at 1.4 billion pounds (635 million kilograms) (CEC, 1996) – see Figure 9.15. Electrical transformers and capacitors accounted for 61 percent of PCB use prior to 1971, and 100 percent of PCB use from 1971-1979 (NAS, 1979).

PCBs are composed of two benzene rings and from 1-12 chlorine atoms (see Figure 9.14). Such a structure affords up to 209 possible permutations, which are termed *congeners*. Commercial PCB formulations have specific mixtures of congeners. The commercial mixtures used within the US have the trade name of *Aroclors*. Seven Aroclor formulations (1016, 1221, 1232, 1242, 1248, 1254, and 1260) account for 98 percent of the PCBs sold in the US since 1970. Aroclor numbers (except 1016) can be interpreted as follows: first 2 digits refer to the number of carbon atoms present (two benzene rings contain 12 carbon atoms), while the later 2 digits is the approximate weight percentage of chlorine (i.e., Aroclor 1242 is approximately 42 percent chlorine). The three Aroclor formulations most often associated with contamination sites are Aroclors 1242, 1254, and 1260 (see Figure 9.13).

PCBs were first recognized as potential environmental contaminants by a Swedish researcher in the mid-1960s. Studies indicated PCB accumulation in several hundred pike collected throughout Sweden, and in one eagle (Jensen, 1966). Since that time, many studies have documented bioaccumulation of PCBs in fish and wildlife throughout the environment. PCBs are known to cause cancer in laboratory animals, and are suspected to cause cancer in humans (USDOH, 1993). Oral exposure, through consumption of contaminated food, is believed to be the major route of PCB exposure in the general population (USDOH, 1993).

PCB regulation began in the US in the mid to late 1970's under the Toxic Substances Control Act. Under current regulation, PCBs are banned from manufacture, import, export, and use except under limited circumstances. PCB-containing products or equipment are regulated based on concentration. The most stringent regulation applies to products with PCB concentrations greater than or equal to 500 ppm - regulations include limited disposal options, and storage, marking, location, and record keeping requirements (CEC, 1996). PCB releases are also regulated by the Clean Air Act, Clean Water Act, Resource Conservation and Recovery Act (RCRA), and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

Figure 9.14: PCB Structure



From:
http://www.atsdr.cdc.gov/

Figure 9.15: US Domestic PCB Sales (NIOSH, 1975)

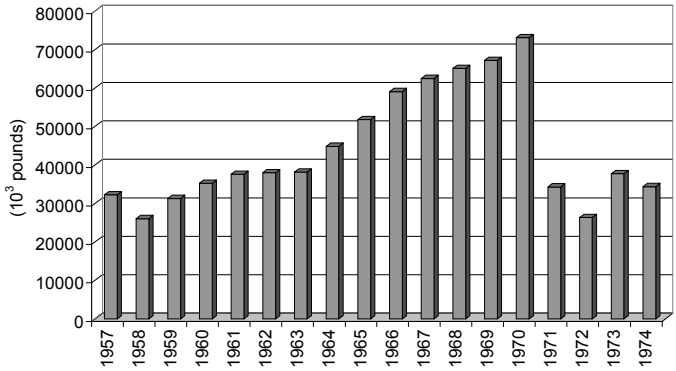
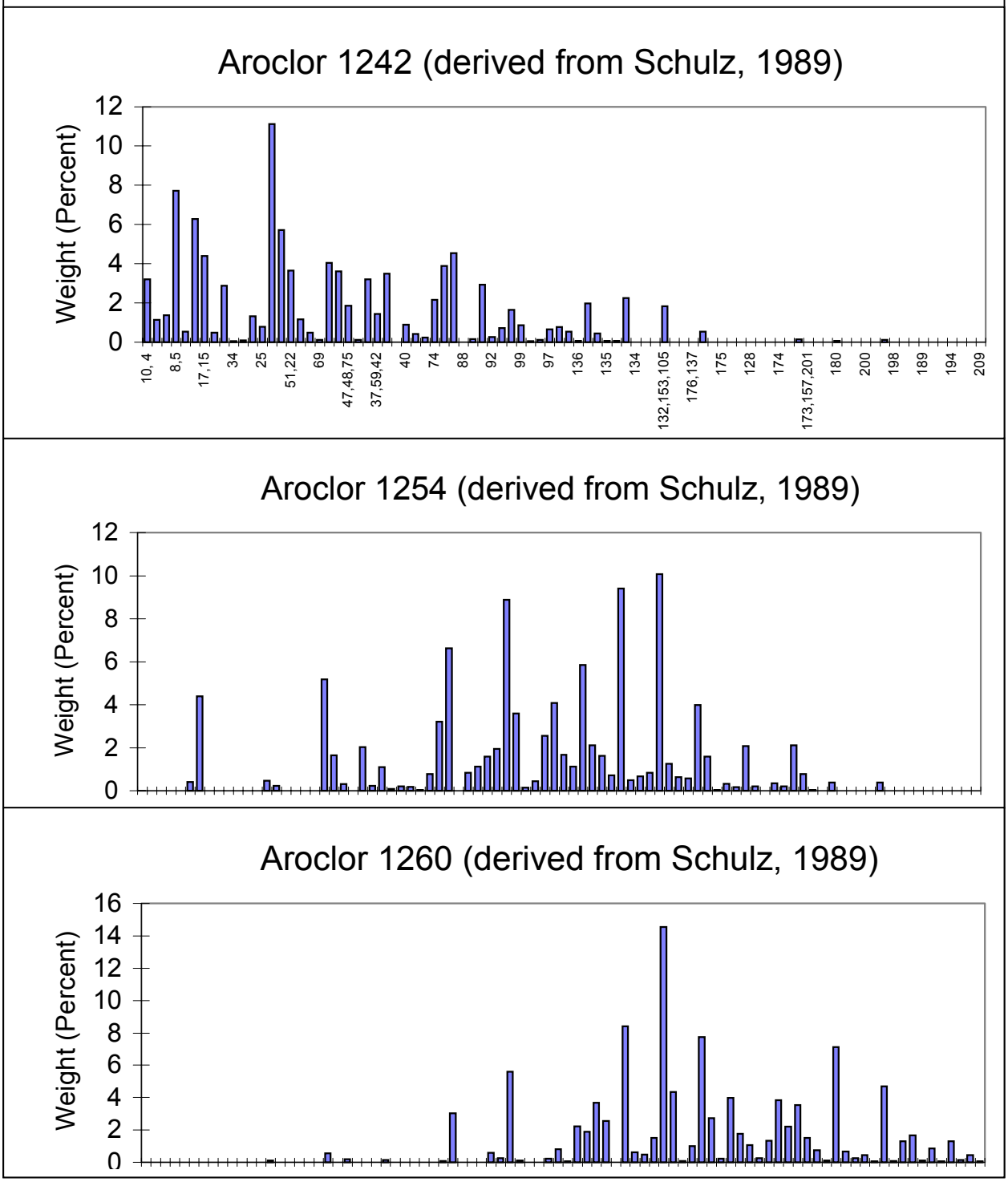


Figure 9.13: Congener pattern for various PCB Aroclor formulations (from Schulz, 1989)



PCB results do not indicate any spatial patterns within the Finger Lakes. However, the congener patterns in several of the Finger Lakes cores (Figure 9.16) suggest differences in contaminant patterns. Once again, while all three core segments were collected from a similar sediment depth (4-6 cm), the time periods represented by the segments vary due to differences in sediment deposition rates within each lake. The Conesus Lake core segment represents sediments deposited during the mid 1980s, while the core segments from Canadice and Seneca Lakes, represent sediments deposited during the early 1970s and the late 1970s, respectively. While as mentioned above, laboratory assessment of Aroclors were all below detection levels with the exception of a single core segment from Canadice Lake, the congener data does appear to provide some clues as to possible parent compounds. Thus, comparison of congener patterns observed within the lakes (Figure 9.16) to those of commercial products in most common use within the United States (Figure 9.13), provides some perspective with respect to possible contaminant sources. The congener profiles from Conesus Lake and Canadice Lake (Figure 9.16) most closely resemble Aroclor 1242 (Figure 9.13) – note the preponderance of lower chlorinated congeners. It is important to note that an exact pattern match between environmental samples and commercial products is very unlikely due to environmental weathering of the chemical signal, and that the best that can be expected is a general resemblance. One unexpected finding worth noting in the Canadice Lake core is that the congener pattern observed in the 4-6 cm section (Aroclor 1242) is different from both the fish flesh pattern observed during the past decade, or so, and from the pattern observed in the core segment immediately above (2-4 cm) which were considered consistent with higher chlorinated Aroclor compounds (Aroclor 1254 and/or 1260). The congener pattern in the Seneca Lake core segment (Figure 9.16) is somewhat more complex than that from the other two lake cores discussed above. The pattern would suggest the presence of two Aroclors – note the peaks on both the left and middle portions of the plot. The left-most pattern is again indicative of Aroclor 1242 (see Figure 9.13), historically the most widely used Aroclor product within the United States. The middle portion of the plot most closely resembles Aroclor 1254 (see Figure 9.13). For example, the largest peak in this portion of the plot (IUPAC-118) represents approximately 8 percent of the total congener mass of the sample while it represents approximately 7 percent of Aroclor 1254. Thus, the Seneca Lake findings indicate that PCB inputs to the lake may originate from more than one source.

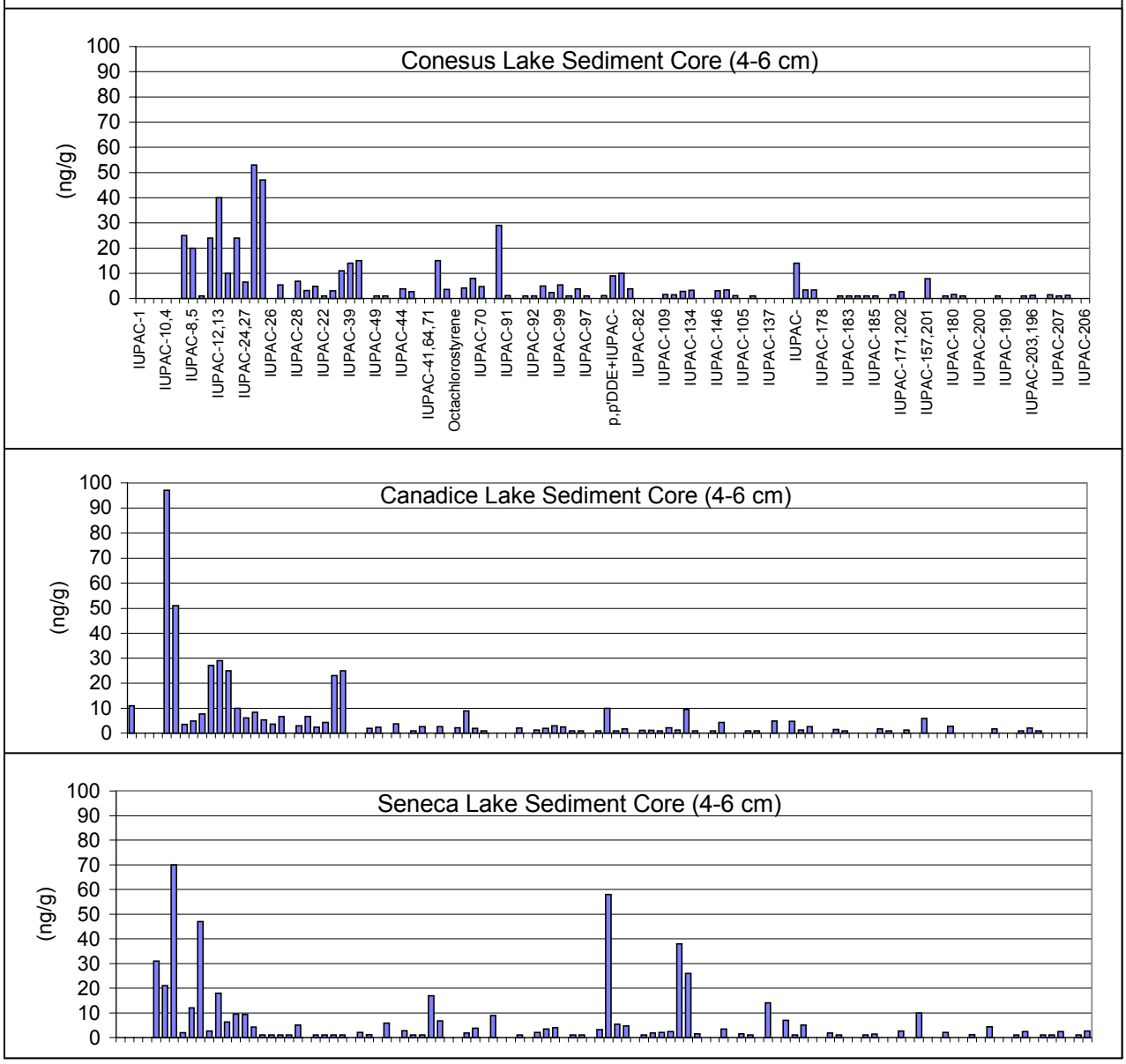
The lack of detectable Aroclors precludes evaluation of temporal PCB trends within the Finger Lakes. In retrospect, it would have been advisable to analyze several sediment core segments using the congener method.

With respect to sediment quality assessment values, the PCB congener totals indicate that all of the Finger Lakes, for which PCB congener data is available, exceed the TEL (34.1 ppb) for PCBs and that a number of the lakes (Skaneateles, Owasco, Seneca, Keuka, Canadice, and Conesus Lakes) exceed the PEL (270 ppb) for total PCBs. Furthermore, while no congener information was available for Canandaigua Lake, it is likely that it would also exceed the TEL and possibly the PEL, given the existing fish consumption advisory. The fact that the sediments in many of the Finger Lakes show elevated levels of PCBs is probably indicative of a diffuse source (e.g., atmospheric) of PCBs to the basins. However, the pattern differences observed in Seneca Lake may indicate some local influence. Furthermore, the relatively low productivity in many of these lakes probably contributes to the observed elevations in that concentrations are reported on a weight per weight basis.

Other Organic Chemicals

The only other organic contaminant found in any of the Finger Lakes cores was Dieldrin. Dieldrin, also an organochlorine pesticide, was historically used for termite control, corn pests, and control of moths (clothing and carpets). Dieldren was banned in the United States in 1974 except for termite control. Dieldrin was found in only a single sediment core segment taken from Canadice Lake. Judging from the level observed (6 ppb) and the depth of occurrence (6-8 cm, ~ 1963), it is likely that Dieldren is of little environmental concern within the Finger Lakes.

Figure 9.16: PCB congener pattern for selected Finger Lakes



d. Inorganic Chemical Findings

Inorganic substances analyzed during this investigation are shown in Table 8.3. In contrast to the organic substances discussed previously, the inorganic substances discussed below can originate from either natural or human processes and/or activities. A listing of the relative quantities (in parts per million) of certain of these elements in the earth's lithosphere (earth's crust) is presented in Table 9.7. Obviously, the concentration of these elements within the earth's crust varies spatially, however, these values provide some perspective regarding the relative abundance of these elements within nature.

Table 9.7: Concentration of selected elements in Earth's Lithosphere (Gammel, 1998)

Element	*Symbol*	*Atomic Number*	*Atomic Weight*	*Concentration (ppm)*	*Percentage*
Arsenic	As	33	74.92	1.5	1.5×10^{-4}
Cadmium	Cd	48	112.40	0.11	1.1×10^{-5}
Calcium	Ca	20	40.08	41,000	4.1
Chromium	Cr	24	52.00	100	1.0×10^{-2}
Copper	Cu	29	63.54	50	0.5×10^{-2}
Lead	Pb	82	207.2	14	1.4×10^{-3}
Manganese	Mn	25	54.94	950	9.5×10^{-2}
Mercury	Hg	80	200.6	0.05	5.0×10^{-6}
Nickel	Ni	28	58.71	80	8.0×10^{-3}
Zinc	Zn	30	65.37	75	7.5×10^{-3}

More than two dozen inorganic chemicals were investigated during this study. However, sediment quality assessment values are available for only a subset of them (see Table 9.8). The relevant assessment values for these compounds are listed in Table 9.8. As with the organic compounds discussed earlier, two assessment values (TEL and PEL) are presented. The reference values are taken from Smith, et al. (1996). These assessment values are believed to be appropriate for evaluating the chemical findings from the Finger Lakes sediment cores. Historical (deep sediment) levels of these chemicals from other parts of New York State are presented in Table 9.9.

Given the large number of analytes assessed during this investigation, the limited availability of assessment values, and space constraints, discussion of results is limited to: (a) those chemicals for which sediment quality assessment values are available; and (b) two additional chemicals (calcium and manganese) which provide additional insight regarding lake chemistry within the Finger Lakes.

Table 9.8: Inorganic sediment assessment values

Substance	TEL (ppm)	PEL (ppm)
Arsenic	5.9	17
Cadmium	0.6	3.53
Chromium	37.3	90
Copper	35.7	197
Lead	35	91.3
Mercury	0.17	0.49
Nickel	18	36
Zinc	123	315

TEL: threshold effect level (Smith, et al., 1996)
PEL: probable effect level (Smith, et al., 1996)

Table 9.9: Historical inorganic chemical levels in NY State sediments (Estabrooks, unpublished data)

Element/Information	NY Harbor (fine grained)	Oswego River (coarse grained)
Arsenic (ppm)	na	0.95
Cadmium (ppm)	0.5	0.6
Chromium (ppm)	60	3.8
Copper (ppm)	25	7.9
Lead (ppm)	20	1.7
Mercury (ppm)	0.3	0.09
Nickel (ppm)	35	3.7
Zinc (ppm)	80	8.8
Carbon (percent)	5	na
Est. Age (years)	500	300

Arsenic

Arsenic (As) is a naturally occurring element in the Earth's crust and is also generated by certain human activities (both current and historical). Arsenic can enter aquatic environments as a result of naturally induced weathering of arsenic containing rock formations. Anthropogenic activities which can result in the release of arsenic to the environment range from arsenic-based insecticides to the burning of fossil fuels – see box below for additional information.

Arsenic was detected in all 11 of the Finger Lakes sediment cores. However, arsenic concentratios varied markedly (more than 4 fold) between the lakes. Table 9.10 provides a summary of arsenic findings for each of the lakes – the table provides a listing of peak arsenic levels and associated sediment depths, as well as surficial sediment concentrations for each of the Finger Lakes. There was no discernable spatial pattern for arsenic levels within the Finger Lakes. The highest sediment arsenic concentrations were observed in surficial sediments from Keuka Lake and Canandaigua Lake. Somewhat lower arsenic levels were observed in surficial sediments from Skaneateles Lake and Canadice Lake. Hemlock Lake also showed substantial sediment arsenic concentrations, however, temporal patterns were not available due to poor radiometric profiles. Sediment core arsenic results for a number of the Finger Lakes are presented in Figures 9.19 and 9.20 - the figures show sediment core arsenic concentrations versus sediment depth.

Table 9.10: Arsenic summary for Finger Lakes sediment cores

Lake	*Peak Arsenic (ppm)*	*Surface Arsenic (ppm)*	*Comments*
Otisco	11 @ 3-4 cm	< 10	surface sediment below detection
Skaneateles	34 @ surface	34	
Owasco	14 @ 3-4 cm	10	
Cayuga	12.5 @ surface	12.5	no temporal significance due to disturbance
Seneca	19 @ surface	19	
Keuka	47.1 @ surface	47.1	highest peak and surface As levels
Canandaigua	45 @ surface	45	2nd highest peak and surface As levels
Honeoye	19.4 @ 6-9 cm	17.1	
Canadice	29.3 @ surface	29.3	
Hemlock	21.4 @ surface	21.4	no temporal significance due to disturbance
Conesus	20.2 @ 4-6 cm	16.9	
TEL	5.9		
PEL	17.0		

In general, temporal trends in sediment arsenic levels within the Finger Lakes indicate increasing concentrations over the past several decades. As shown in Table 9.5 above, 5 of the 9 Finger Lakes with intact sediment chronologies (Skaneateles, Seneca, Keuka, Canandaigua, and Canadice Lakes) show arsenic peaks within surficial sediment layers. Furthermore, 3 additional lakes (Otisco, Owasco, and Conesus Lakes) demonstrate higher arsenic levels in the upper half of the sediment cores. Similar trends in arsenic levels have been observed in Lake Champlain (Lassel, 1996). While the reason(s) for the upward trend in arsenic levels in upper sediment layers is not certain, there are several plausible hypotheses.

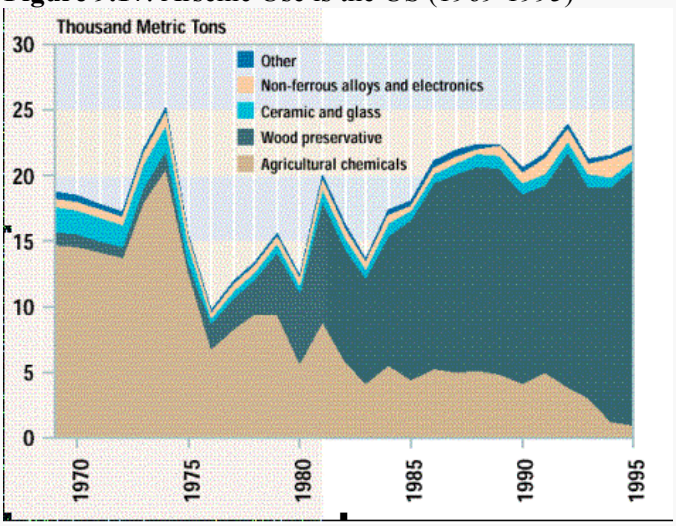
Arsenic

Arsenic (As) has been used as an insecticide for centuries. Some evidence suggests that the Chinese used arsenic as an insecticide as early as 200 BC (US Army, 2000). More recent use figures for the United States are included in Figure 9.17. In general, prior to 1975, agricultural use was the predominant anthropogenic source of arsenic to the environment, however, from 1975 to the present agricultural use of arsenic has declined while wood preservative applications have increased markedly. Arsenic compounds used in wood preservation include chromated copper arsenate (CCA) and ammoniacal copper arsenate (ACA). The burning of fossil fuel is also a significant source of arsenic to the environment. Arsenic may also reach aquatic systems via natural processes such as the dissolution of mineral and/or rock deposits containing arsenic.

Arsenic is a naturally-occurring mineral, and is considered a transitional metal, or metaloid, with respect to its position in the Periodic Table. This suggests that arsenic can behave as either a metal or a non-metal. The primary arsenic species found in natural waters are arsenate ions (oxidation state +V) which are most prevalent in aerobic waters and arsenite ions (oxidation state +III) which are most common in anaerobic waters. The two species show significantly different chemical behavior. One particularly important difference is that arsenate behaves similar to phosphate in aquatic systems, which can have significant implications for biotic uptake and availability. Arsenic can occur in both inorganic and organic forms. The principal forms of arsenic and their cycling through the aquatic environment are depicted in Figure 9.18. Arsenic toxicity varies, in general the trivalent (+III) compounds are considered more toxic than the pentavalent (+V) compounds.

As with DDT, arsenic is featured prominently in Rachel Carson's Silent Spring (Carson, 1962). Arsenic exhibits both acute toxicity (neuro-toxin) and chronic toxicity (carcinogenicity). Arsenic has long been known to be a neurotoxin. This is the principal mechanism by which arsenic acts as a pesticide. With respect to chronic toxicity, arsenic has been linked to cancers of the skin, liver, bladder and lung. The United States Environmental Protection Agency (EPA) is currently in the process of evaluating the maximum contaminant level (MCL) for arsenic in drinking water supplies. EPA is reviewing the MCL for arsenic because of concerns that it may not be sufficiently protective of human health. The proposed MCL is 10 ug/l, which would be a 5-fold reduction from the existing MCL of 50 ug/l.

Figure 9.17: Arsenic Use is the US (1969-1995)



Source: Interagency Working Group on Industrial Ecology, 1998

Figure 9.18: Arsenic Cycle (from Sohrin, 1997)

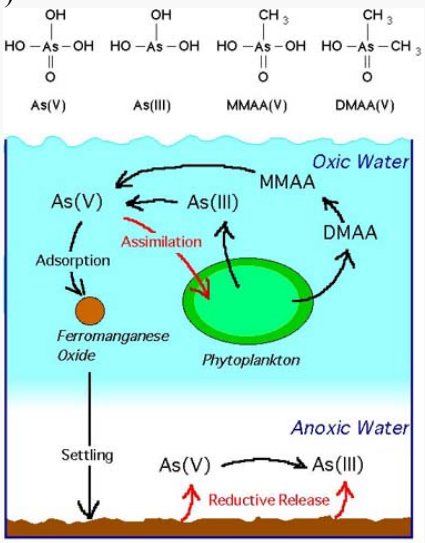
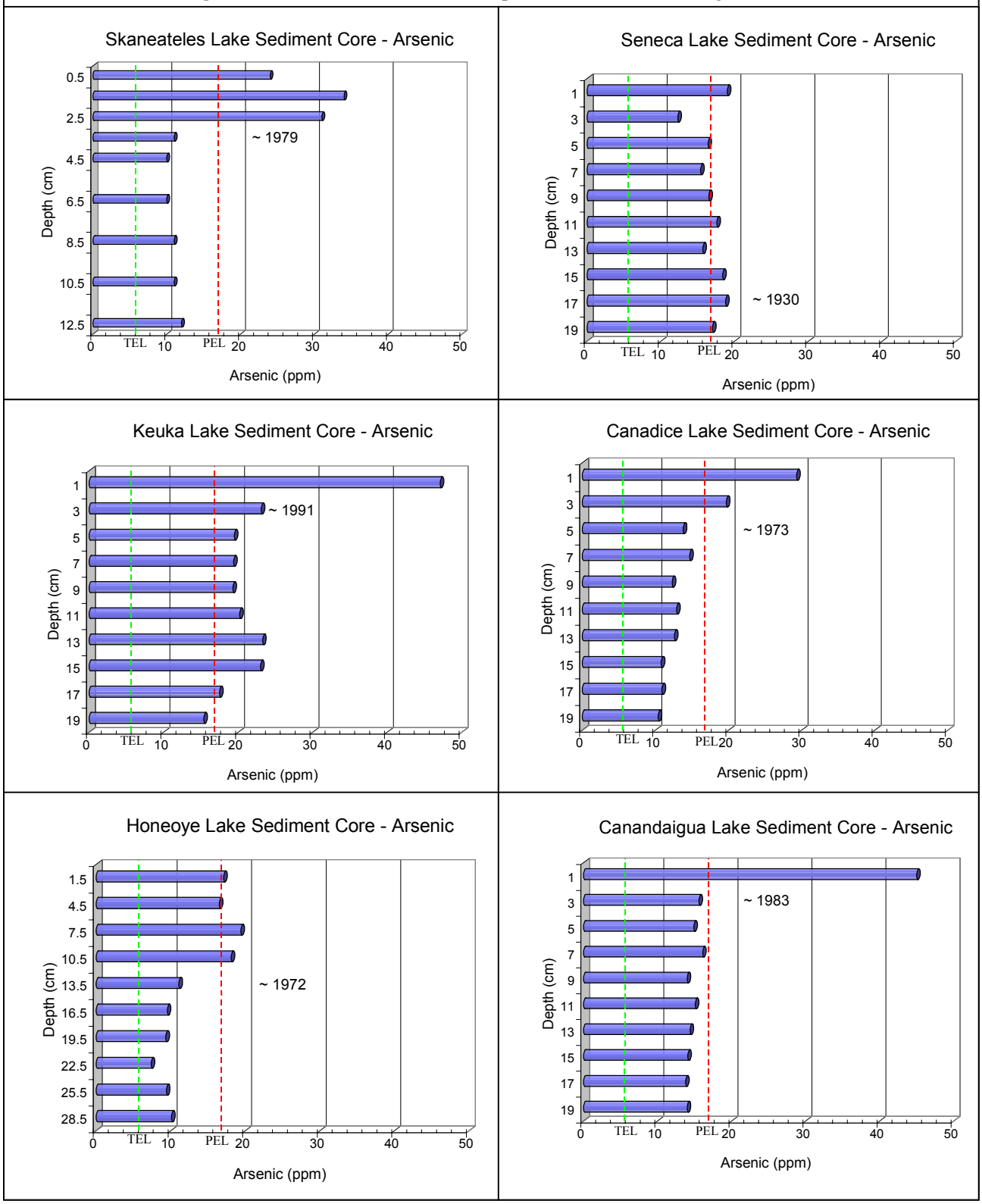


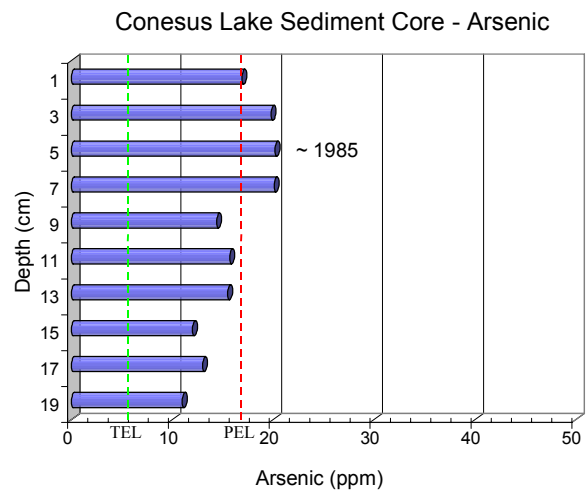
Figure. Arsenic cycle in lake water.

Figure 9.19: Sediment core arsenic profiles for selected Finger Lakes



First, it is conceivable that the increase in arsenic concentration in the upper sediments of these lakes is the result of decreased primary productivity within these systems. Arsenic concentrations within the sediments are recorded on a weight per weight basis (ug/kg). If one assumes a constant input of arsenic to a lake, then, as the mass of other material being contributed to the bottom sediments is reduced (due to decreased algal productivity, etc.), the concentration of arsenic within the sediments, on a weight per weight basis, would tend to increase. Thus, one would expect an inverse relationship between sediment arsenic concentration and primary productivity for a given lake. There are several lines of evidence that lend support to this hypothesis. For instance, the increases in arsenic levels coincide temporally, to a degree, with reductions in lake trophic indicators. The arsenic increases appear within the past 2-3 decades and are thus consistent (temporally) with reductions in phosphorus loadings as discussed earlier. Furthermore, those lakes (Otisco, Honeoye, and Conesus Lakes) that have shown little or no reduction in trophic conditions, also exhibit less pronounced increases in arsenic levels, or no recent spike in arsenic levels. Furthermore, the magnitude of change in both sediment arsenic concentration (~ 2-3 fold increase) and primary productivity (~ 2-3 fold decrease as measured by chlorophyll *a*) are approximately equivalent in those lakes exhibiting arsenic enrichment. One line of evidence that would appear to work against such a hypothesis is that one would expect other compounds (with a constant rate of supply over time) to mimic the arsenic patterns. The only inorganic chemical to show a similar chronological pattern as arsenic is manganese, and this parallel might have an alternative explanation – see below.

Figure 9.20: Conesus sediment core arsenic profile



S*econd*, it is possible that there is an upward migration of arsenic within the sediments due to reduction/oxidation conditions within the benthos. The solubility of arsenic in water is influenced by dissolved oxygen levels – in general, as dissolved oxygen levels increase arsenic solubility decreases, and visa versa. A similar relationship exists for several other elements (e.g., phosphorus, manganese, etc.). Thus, in well-oxygenated lakes, the upper sediment layer of the benthos remains oxygenated, thereby restricting the solubility of arsenic in the pore waters of these sediments. In contrast, lower sediment layers, being largely devoid of oxygen (due to oxygen consumption and lack of replenishment), show increased arsenic solubility in pore waters. This disparity in pore water solubility would theoretically establish a vertical *concentration gradient* within the benthic sediments - with lower pore water arsenic concentrations within surface sediments and higher pore water arsenic concentrations within the deeper sediments – resulting in an upward migration of arsenic within the sediments. However, once the arsenic reaches the surficial sediment layer (which remains oxygenated in many of the study lakes) it precipitates out of solution and is incorporated within the benthic sediments. There are several lines of support for this hypothesis. First, other researchers have observed a similar upward migration for manganese within the bottom sediments of aquatic systems (Williams, et al., 1978), and, as will be discussed below, manganese was found to show very similar patterns to arsenic within the Finger Lakes. In addition, USGS research conducted on Cayuga Lake cores found differences in pore water arsenic concentrations with depth – with maximum pore water arsenic concentrations at between 35-50 cm depth (Kraemer, unpublished data).

Third, it is the possible that arsenic loading to the Finger Lakes has increased over the past several decades due to either anthropogenic activities or natural processes. For example, it is conceivable that acid rain within the watersheds may be accelerating the leaching of arsenic from underlying rock strata. Alternatively, either current arsenic use or historical (buried) sources may be contributing to arsenic loading within the watersheds.

Fourth, in some of the lakes, observed arsenic increases coincide temporally with the invasion of Zebra mussels. It is conceivable that Zebra mussel populations are altering the processing of arsenic within the lake ecosystem. As alluded to earlier, Zebra mussels are extremely efficient at scavenging particulate material from the water column. In effect, Zebra mussels behave like filters within a water body, and short circuit the normal processing of particulate material.

Regardless of cause(s), the arsenic spikes at the top of these sediment cores raise several environmental concerns. The arsenic levels observed within the sediments of certain Finger Lakes cores exceed current sediment quality assessment values. The surficial sediments from Canadice, Canandaigua, Keuka, Seneca, and Skaneateles Lakes exceed the PEL (17 ppm), while the surficial sediments from most of the other Finger Lakes exceed the TEL (5.9 ppm). The presence of arsenic in surficial sediments raises the following concerns: (a) possible availability of arsenic to the overlying water column through diffusion; and (b) availability of arsenic to the benthic biotic community. As discussed in the box above, there is currently a heightened concern about arsenic toxicity, and the USEPA is currently in the process of revising the MCL for arsenic.

Given these findings, and the fact that 10 of the 11 Finger Lakes serve as public water supply sources, water column sampling for arsenic was initiated in 1999 as part of the Synoptic Investigation. Findings were generally encouraging - only one sample showed detectable levels of arsenic (Owasco Lake epilimnetic sample from September 1999 at 10 ug/l). However, several caveats are in order regarding these findings: (a) analytical detection limits for the water samples were 10 ug/l, which is at the currently proposed MCL; (b) sampling was conducted at our prescribed sampling locations which included both epilimnetic and hypolimnetic samples, however, the hypolimnetic sample depth is, by definition, 2/3rds the station depth – thus, it is conceivable that arsenic concentrations could be higher nearer the lake bottom due to diffusion from the benthos; and (3) sample collection was quite limited (spatially and temporally) due to resource limitations.

Cadmium

Cadmium is found in relatively low concentrations in the earth's crust. Anthropogenic sources of cadmium include metal-plating operations, battery manufacture, pigment production, and plastics manufacturing. It can also be found in fairly high concentrations in sewage sludge. Cadmium is considered a potential human carcinogen, and has also been shown to cause other adverse health effects including kidney damage, bone defects, high blood pressure, and reproductive problems.

Detectable levels of cadmium were found in Conesus, Canadice, Seneca, and Cayuga Lakes (see Table 9.11). Cadmium levels in these cores ranged from below detection to 3.43 ppm. The highest observed cadmium concentration (3.43 ppm) was from Conesus Lake in the 2-4 cm core segment. Other core segments from Conesus Lake were below detectable levels. Unfortunately, analytical detection levels for core samples collected from the 3 eastern lakes (Otisco, Skaneateles, and Owasco Lakes) were relatively high (in certain instances above the PEL) and all samples came back as below detection. Thus, conclusions regarding cadmium levels for these lakes, or comparisons including these lakes, are not appropriate.

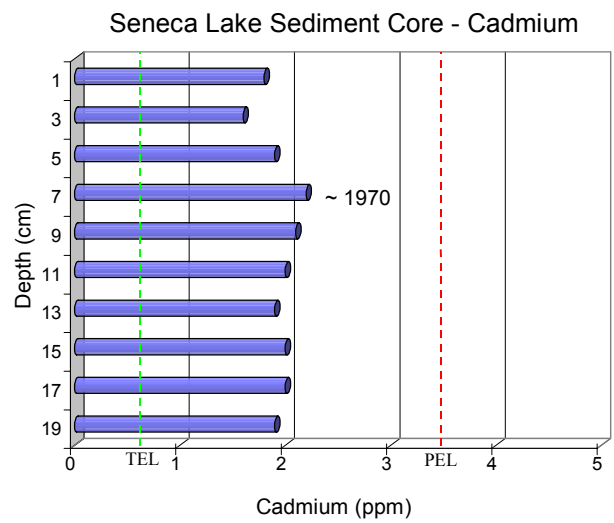
Table 9.11: Cadmium in Finger Lakes sediment cores

Lake	*Peak Cd (ppm)*	*Depth(cm)/Age*
Otisco	below detection	na
Skaneateles	below detection	na
Owasco	below detection	na
Cayuga	0.8	na
Seneca	2.2	6-8 cm (1970)
Keuka	below detection	na
Canandaigua	below detection	na
Honeoye	na	na
Canadice	1.4	6-8 cm (1963)
Hemlock	below detection	na
Conesus	3.4	2-4 cm (1990)
TEL	0.6	na
PEL	3.53	na

Due to the large number of analytical non-detects, temporal trends in cadmium levels are only discernable from the Seneca Lake core. The vertical profile for cadmium in the Seneca Lake sediment core is depicted in Figure 9.21. The trend indicates a slight decline in cadmium levels over time, beginning with a cadmium peak in approximately 1970.

Certain sediment core segments from each of the 4 lakes in which cadmium was detected (Cayuga, Seneca, Canadice, and Conesus Lakes) were above the TEL (0.6 ppm), but all were below the PEL (3.53 ppm) with the exception of a single core segment from Conesus Lake.

Figure 9.21: Seneca Lake sediment core cadmium profile



These findings appear to indicate that cadmium is not a significant environmental concern within the Finger Lakes. Furthermore, the relatively uniform cadmium concentrations observed within the Finger Lakes sediments, would suggest that the source of cadmium to these lakes is diffuse in nature (e.g., atmospheric deposition).

Calcium

Calcium (Ca) is relatively abundant in the earth's crust, and is generally not considered a toxic contaminant. The reasons for including calcium in this discussion are as follows: (1) temporal changes observed during this study may be indicative of ecosystem changes occurring within the Finger Lakes; and (2) findings indicate the potential to exacerbate problems associated with Zebra mussel populations.

The sediment core findings are largely consistent with water column findings presented above, in that sediment calcium levels exhibit significant spatial differences between lakes (see Table 9.12). Sediment calcium peak values varied by nearly an order of magnitude, with a minimum in Canadice Lake and a maximum in Otisco Lake. As with water column findings for major ion species, there is an apparent east/west trend in the calcium levels within the Finger Lakes, probably reflecting watershed soil conditions and underlying geology. In general, calcium levels are higher in the eastern Finger Lakes than in the western lakes. The lake sediments can be grouped into low (< 10,000 ppm), medium (> 10,000 ppm but < 50,000 ppm), and high (> 50,000 ppm) calcium levels based upon maximum calcium levels observed. Otisco and Owasco Lakes fall into the high calcium category, Skaneateles, Cayuga, Seneca, Canandaigua, and Conesus Lakes fit within the medium calcium category, and the remainder of the lakes (Keuka, Honeoye, Canadice, and Hemlock Lakes) fall into the low calcium category. These finding are consistent with water column findings presented above (See Figure 5.19).

Table 9.12: Calcium levels in Finger Lakes sediment cores

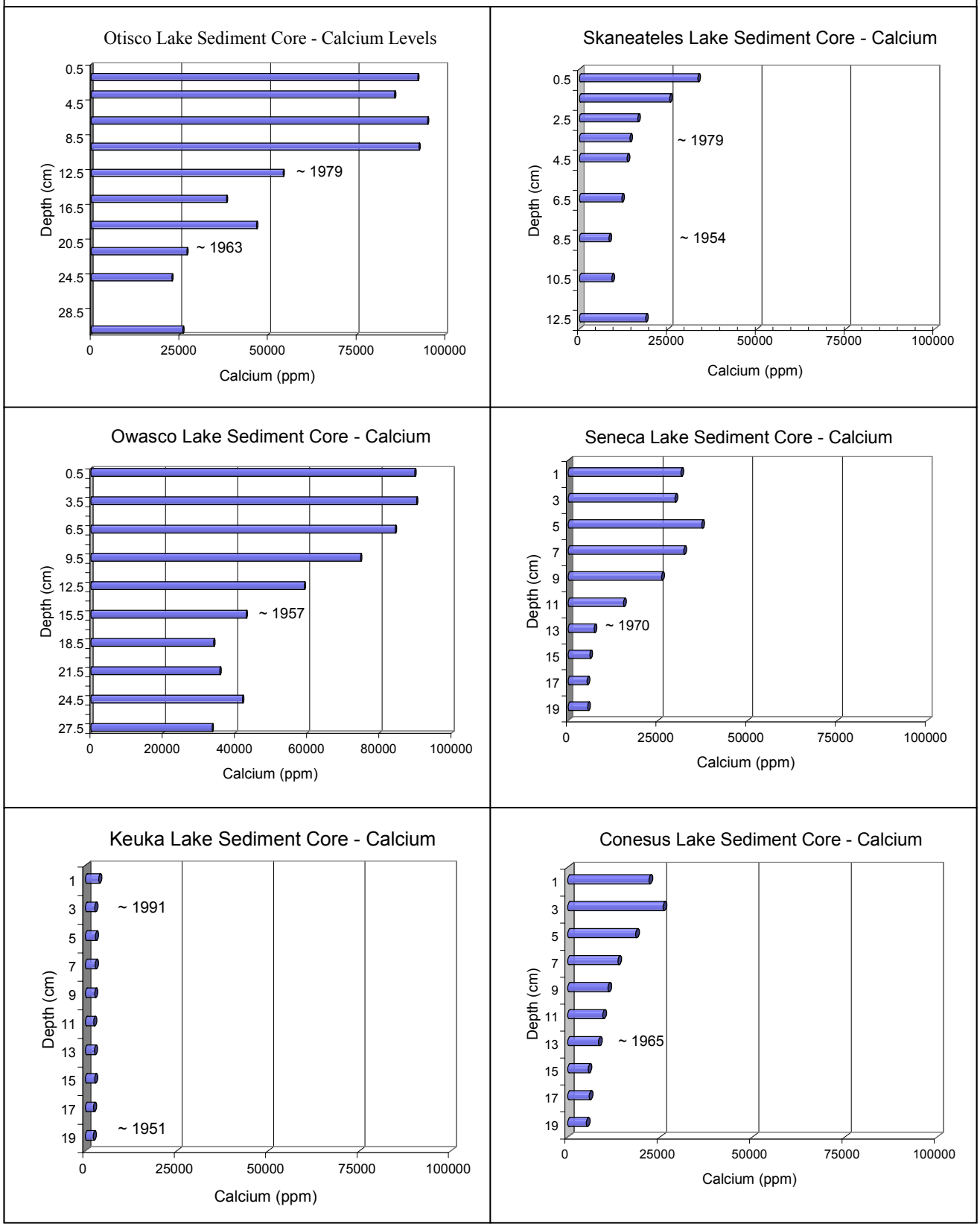
Lake	*Peak Ca (ppm)*	*Depth (cm)/~ Age*
Otisco	94,900	6-7 (1987)
Skaneateles	25,400	1-2 (1989)
Owasco	90,200	3-4 (1987)
* Cayuga	46,100	na
Seneca	37,200	4-6 (1978)
Keuka	3,680	0-2 (1996)
Canandaigua	18,900	14-16 (1923)
Honeoye	4,550	0-3 (1996)
Canadice	2,540	2-4 (1983)
* Hemlock	3,470	na
Conesus	25,800	2-4 (1990)

* Cayuga Lake and Hemlock Lake cores showed disturbed sediment chronologies.

The sediment cores offer some intriguing temporal insights with respect to changes in calcium levels within the Finger Lakes. Sediment core findings for nearly every one of the Finger Lakes (in which intact chronologies were available) show a significant increase in calcium levels over the past half-century. These findings are illustrated in Figure 9.22. Our results suggest significant increases in calcium levels beginning between the mid-1950s to the late-1970s, with peak concentrations occurring within the last two decades. However, our analyses were generally limited to the upper 30 cm of the sediment cores. Researchers from Syracuse University, which participated in this investigation, analyzed calcite concentrations from deeper portions of the cores. Their results indicate that calcite concentrations began to increase in the 1920s and 1930s (Mullins, et al., 2000). Their working hypothesis is that the calcium increases observed over the past half-century or more may be due to the effects of acid rain. It is hypothesized that acid rain accelerates the leaching of minerals (e.g., calcium) within the watershed, and the minerals are then transported to the lake basin. This hypothesis is consistent with other researchers (Lawrence, et al., 1997) who have documented accelerated calcium depletion rates from forest soils.

The implications of the observed calcium changes are not yet clear. However, as discussed earlier, increasing calcium levels within the lake water column could lead to an increase in Zebra mussel populations, which could in turn exacerbate problems associated with these exotic invaders. It is also possible that accelerated leaching of calcium (and other cations) from watershed soils might eventually lead to diminished buffering capacity within certain Finger Lakes (e.g., Canadice Lake). Effects might also extend beyond the lake itself. There are some indications in other areas of the world that acid rain has adversely affected certain forest ecosystems and degraded forest productivity.

Figure 9.22: Calcium profiles for selected Finger Lakes (notice scale differences for Depth)



Chromium

Chromium (Cr) is found at relatively low levels within the earth's crust. Anthropogenic sources of chromium include chrome plating, the manufacture of pigments, leather tanning, and treatment of wood products (recall the discussion of arsenic and the use of CCA). Chromium occurs in the environment in three principal states –chromium (0), chromium (III), and chromium (VI). Chromium (III) occurs naturally in the environment, while chromium (VI) and chromium (0) result primarily from industrial processes. Chromium toxicity varies significantly depending upon the species present. Chromium (III) is the least toxic of the three species, and is actually considered an essential nutrient.

Sediment core findings indicate moderate levels of chromium within the Finger Lakes – see Table 9.13. Results are for total chromium levels and do not differentiate between chromium species. The results suggest some spatial patterns across the lakes. The three eastern lakes exhibit the highest chromium levels. However, it should be noted that analyses for the three eastern lakes sediment cores were conducted at a different laboratory than were the western lake cores. Unfortunately, sample collection for the two sets of lakes occurred in different years and no sample splits were conducted.

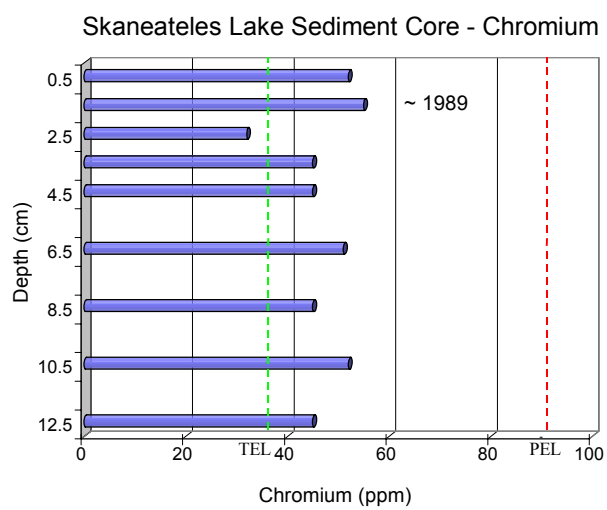
Table 9.13: Chromium in Finger Lakes sediment cores

Lake	*Peak Cr (ppm)*	*Depth (cm)/~ Age*
Otisco	58	25-26 (1962)
Skaneateles	55	1-2 (1989)
Owasco	52	12-13 (1964)
* Cayuga	18.3	na
Seneca	30.1	6-8 (1970)
Keuka	30.2	14-16 (1961)
Canandaigua	27.6	16-18 (1913)
Honeoye	32.5	0-3 (1996)
Canadice	28.6	2-4 (1983)
* Hemlock	30.5	na
Conesus	29.3	16-18 (1955)
TEL	37.3	na
PEL	90	na

* Cayuga Lake and Hemlock Lake cores show disturbed sediment chronologies.

Temporal trends in chromium levels, as interpreted through sediment core profiles, suggest that chromium levels within the Finger Lakes generally peaked between the 1950s and the 1970s. Exceptions to this general trend are Canandaigua Lake (peak about 1913), Skaneateles Lake (peak about 1989) and Honeoye Lake (peak about 1996). In the latter two instances, while the peaks occurred relatively recently, the data do not show a consistent trend. This can be seen in the chromium profile for Skaneateles Lake (see Figure 9.23). While chromium levels peaked in 1989, the level was only slightly higher than in some earlier years.

Figure 9.23: Skaneateles Lake sediment chromium profile



Chromium levels observed in certain Finger Lakes sediment cores segments (primarily, the three eastern lakes) exceed the TEL for chromium. However, none of the core segments exceeded the PEL for chromium.

The significance of the chromium finding is not clear. In general, the results would suggest diffuse loading of chromium to the Finger Lakes, as evidenced by the relatively uniform levels of chromium observed.

Copper

Copper (Cu) is found at relatively low levels within the earth's crust. However, copper is used widely in human activities. This is due to the fact that copper offers a number of attractive industrial properties (e.g., corrosion resistance, malleability, and conductivity). Copper is used extensively in the electrical, plumbing, and automotive industries. Copper, in the form of copper sulfate, has been used historically to control the growth of algae in aquatic systems. Copper is toxic to many freshwater invertebrates and fish. Copper toxicity is influenced by several factors, including water hardness, pH, and the level of organic matter present.

Sediment core findings indicate fairly uniform levels of copper within the Finger Lakes with the exception of Otisco Lake (see Table 9.14). Seven of the Finger Lakes (Owasco, Keuka, Canandaigua, Honeoye, Canadice, Hemlock, and Conesus Lakes) show remarkably similar peak copper levels. Skaneateles and Seneca Lakes show somewhat higher peaks with respect to sediment copper levels. However, Otisco Lake sediments exhibit far higher copper levels than the other Finger Lakes. The copper profile for Otisco Lake is shown in Figure 9.24. The elevations in copper levels are likely the result of copper sulfate treatments for the control algal growth, which have taken place on Otisco Lake for many years. In fact, if one looks at the lower sediments (~ 1955 back) the copper levels are quite consistent with the historical levels observed in most of the other Finger Lakes.

Table 9.14: Copper levels in Finger Lakes sediment cores

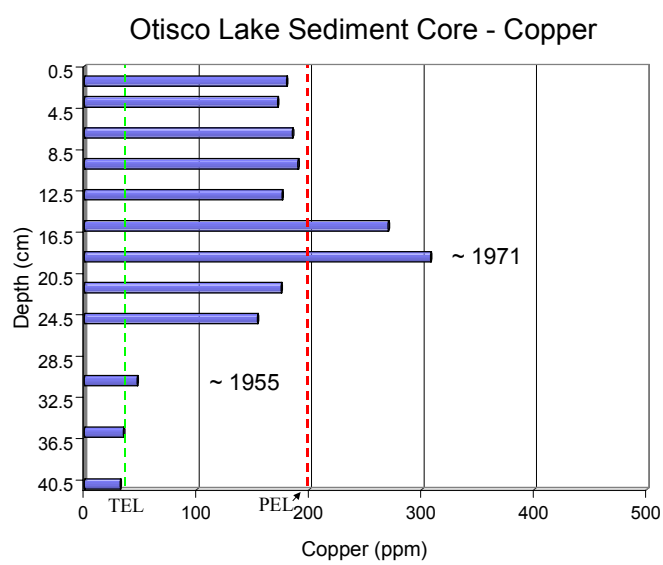
Lake	*Peak Cu (ppm)*	*Depth (cm)/~ Age*
Otisco	308	18-19 (1971)
Skaneateles	78	8-9 (1954)
Owasco	44	0-1 (1995)
* Cayuga	31.4	na
Seneca	61.8	6-8 (1970)
Keuka	45.1	4-6 (1986)
Canandaigua	42.2	2-4 (1983)
Honeoye	44.8	24-27 (1948)
Canadice	45.9	2-4 (1983)
* Hemlock	49.8	na
Conesus	44	10-12 (1970)
TEL	35.7	na
PEL	197	na

* Cayuga Lake and Hemlock Lake cores showed disturbed sediment chronologies.

The temporal trends in copper, as captured in sediment core profiles, are sporadic for most of the Finger Lakes. The only exception to this pattern is Otisco Lake. Otisco Lake shows a marked increase in sediment copper levels in the late 1950s, and a peak in copper levels during the early 1970s. The levels decline somewhat thereafter, but plateau at about four times background levels. Once again, these temporal trends in sediment copper concentrations likely reflect copper sulfate treatments within Otisco Lake.

Most of the Finger Lakes exceed the TEL for copper. Otisco Lake was the only one of the lakes to exceed the PEL for copper, and that was several decades ago.

Figure 9.24: Otisco Lake sediment core copper profile



Lead

Lead (Pb) is relatively rare in the earth's crust. However, lead has been used in human activities for thousands of years. In fact, some theorize that lead poisoning played a role in the demise of the Roman Empire - due to leaching of lead from Roman aqueducts. Lead offers a number of attractive properties for industrial applications including, softness, high density, low melting point, and corrosion resistance.

While lead can reach aqueous environments from natural processes (e.g., erosion of rock, forest fires, etc.), elevated levels are most often associated with human activities. Anthropogenic sources of lead range from lead-based house paint to industrial mining operations. Other sources of lead contamination include lead-based pipes and solder, lead-acid batteries, and lead-based sinkers and shot. However, the most pervasive source of lead to the environment during the past century has been leaded gasoline. Lead was first used as a gasoline additive during the 1920s. The additives tetraethyl and tetramethyl lead were used to prevent engine knock, enhance octane levels, and lubricate engine valves. By the late 1960s and early 1970s, it was apparent that lead had become a widespread contaminant in the environment, and efforts were begun to address the situation. Lead exposure can cause damage to the brain, nervous system, red blood cells, and the kidneys. By the mid 1980s, regulations were in place that curtailed the use of leaded gasoline. As a comparison, in 1979 automobiles released 94.6 million kilograms of lead into the air in the United States, while by 1989 that number had declined to 2.2 million kg – over a 40 fold reduction (USPHS, 1993).

Comparisons of sediment lead levels within the Finger Lakes indicate some spatial differences between lakes (see Table 9.15). Peak lead levels, for those lakes in which intact sediment chronologies were available, ranged from 55 mg/kg in Otisco Lake to 108 mg/kg in Conesus Lake. The highest lead levels observed occurred in Conesus and Skaneateles Lakes, which represent the productivity extremes within the Finger Lakes. In both instances, peak levels occurred approximately 3-4 decades ago. The lowest lead levels observed overall were in the Cayuga Lake sediment core. Recall, however, that the Cayuga Lake core was not considered appropriate for dating purposes due to its poor cesium profile. Thus, the peak lead level in Cayuga Lake should be viewed as a composite value. Furthermore, there are indications that lead may be a concern in the southern end of Cayuga Lake. For example, there is an ongoing investigation of a contamination site in Ithaca, adjacent to Fall Creek, which is believed to contain significant levels of lead. Furthermore, sediment investigations within the southern end of Cayuga Lake showed elevated lead levels (123 ppm) on the east side of the lake (Sterns and Wheler, 1997).

Table 9.15: Lead in Finger Lakes sediment cores

Lake	*Peak Pb (mg/kg)*	*Depth (cm)/~ Age*
Otisco	55	24-25 (1963)
Skaneateles	102	6-7 (1964)
Owasco	73	12-13 (1965)
* Cayuga	26.3	na
Seneca	84.6	6-8 (1970)
Keuka	69.4	12-14 (1966)
Canandaigua	78	6-8 (1963)
Honeoye	62.9	12-15 (1972)
Canadice	64.2	4-6 (1973)
* Hemlock	52.5	na
Conesus	108	10-12 (1970)
TEL	35	-
PEL	91.3	-

* Cayuga Lake and Hemlock Lake cores showed disturbed sediment chronologies.

Sediment core lead profiles for a number of the Finger Lakes are shown in Figures 9.25 and 9.26.

Figure 9.25: Lead profiles in sediment cores from selected Finger Lakes - 1 (note scale differences)

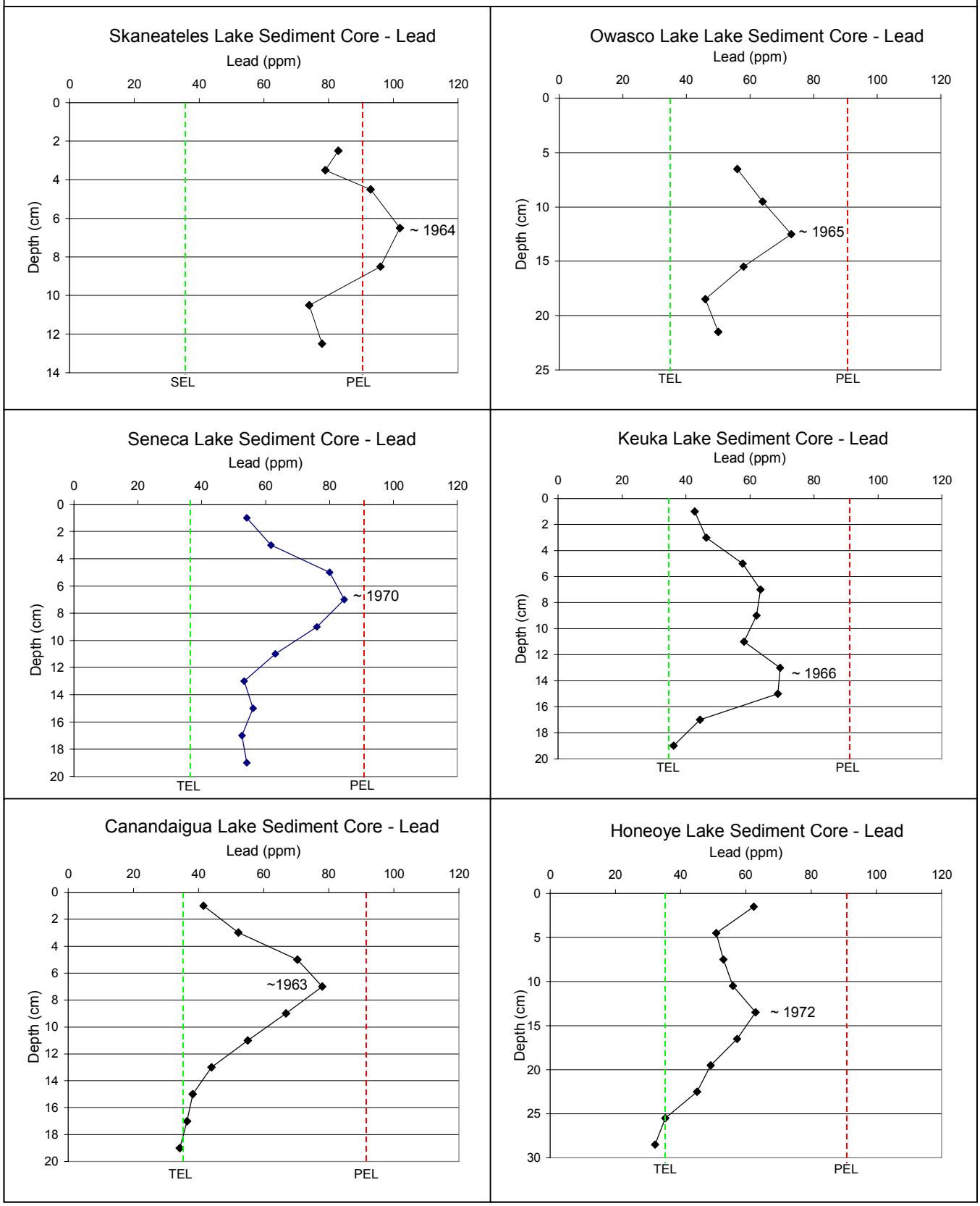
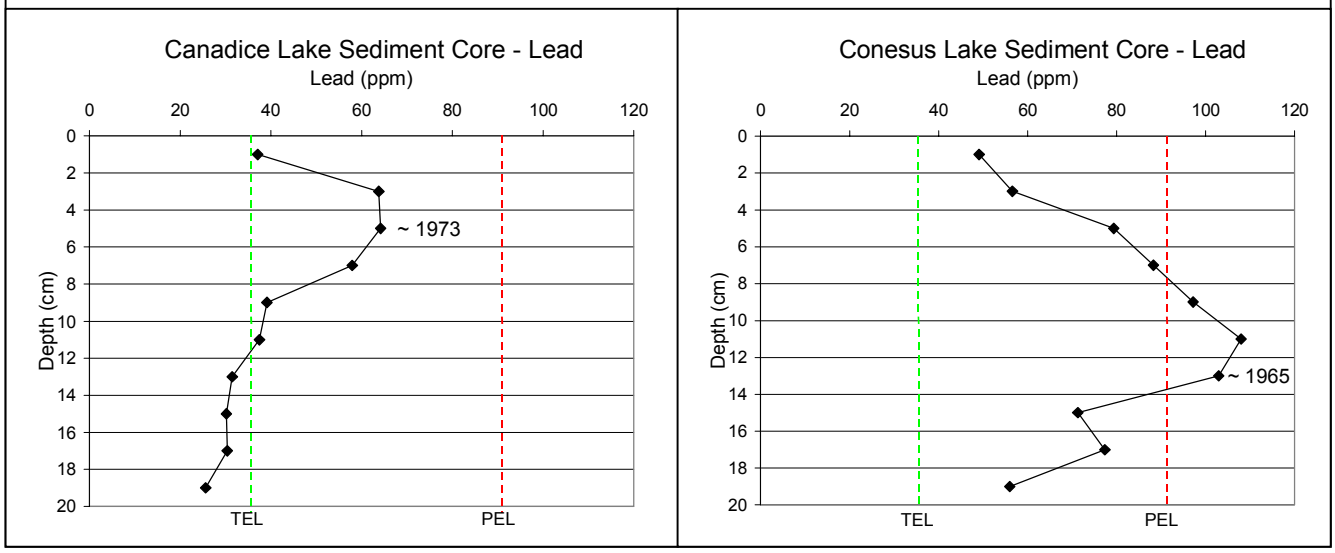


Figure 9.26: Lead profiles in sediment cores from selected Finger Lakes - 2



Temporal trends for lead within the Finger Lakes sediment cores indicate a predominantly downward trend. Findings from all of the lakes, in which intact sediment cores were obtained, indicate that maximum lead levels occurred between the mid-1960s and the mid-1970s. Furthermore, with the exception of Honeoye Lake, all of the lakes exhibit a pronounced decline in lead levels over the past 3-4 decades. It is interesting to note the rather narrow range in peak lead levels observed (~ 70-110 mg/kg), which would appear to support the notion of a widespread loading source (e.g., leaded gasoline). This is also consistent with the phasing-out of leaded gasoline within the United States during the past several decades. As noted above, the only exception to the downward trend in lead levels is Honeoye Lake. While Honeoye Lake does show a significant decline in lead levels between the mid-1970s and the late 1980s, there is a recent up-tick in lead levels (as shown in the most recent core segment). The lead level observed in the most recent core segment is close to the peak value observed in the early 1970s. The cause and/or validity of this recent upturn in lead levels within Honeoye Lake are not certain.

While lead levels have declined markedly within the Finger Lakes over the past several decades they remain, for the most part, above the TEL. However, none of the Finger Lakes surficial core segments exceed the PEL for lead – although deeper sediments within Conesus and Skaneateles Lakes do exceed the PEL.

It is unclear from our findings whether lead levels will continue to decline or whether they have reached a plateau. The question of "background" lead concentrations within the Finger Lakes is not entirely answerable. For example, note that observed "background" levels (background is in quotations because it is unclear if the deepest core segments represent true background conditions) range from approximately 30 ppm on Canadice Lake (ca. 1903) to approximately 80 ppm on Skaneateles Lake (ca. 1934). Obviously, the Canadice Lake core segment is from an earlier date than is the Skaneateles Lake core segment. Thus, the lead levels observed within the deep sediments of Canadice Lake are probably a better representation of actual background concentrations within the Finger Lakes, given their earlier vintage and lower concentration. This may indicate that lead levels within several of the Finger Lakes remain elevated above historical background levels.

Manganese

Manganese (Mn) is moderately abundant in the earth's crust. It is used in the production of steel, batteries, and ceramics. In addition, manganese, in the form of methylcyclopentadienyl manganese tricarbonyl (MMT), is used to enhance octane levels in gasoline. MMT is one of the substances used to replace lead compounds in gasoline. Manganese is an essential nutrient, however, it can have toxic effects at elevated concentrations. It can have adverse effects on the nervous system, lung, and reproductive system.

The Finger Lakes sediment cores collected for this study show substantial spatial variation in manganese levels (see Table 9.16). Peak levels vary by nearly 5 fold, ranging from 1,800 ppm in Canadice Lake to 8,810 ppm in Skaneateles Lake – this excludes Cayuga and Hemlock Lakes due to disturbed sediment chronologies discussed above. There was no apparent east-west trend in the data, nor were manganese levels significantly correlated to lake size or lake productivity level.

Table 9.16: Manganese in Finger Lakes sediment cores

Lake	*Peak Mn (ppm)*	*Depth (cm)/~ Age*
Otisco	1710	9-10 (1983)
Skaneateles	8810	0-1 (1994)
Owasco	3630	0-1 (1995)
* Cayuga	940	na
Seneca	2450	0-2 (1994)
Keuka	5650	0-2 (1996)
Canandaigua	4960	0-2 (1993)
Honeoye	2410	0-3 (1996)
Canadice	1800	0-2 (1993)
* Hemlock	2550	na
Conesus	3490	10-12 (1970)
TEL (LEL)	na	-
SEL	na	-

* Cayuga Lake and Hemlock Lake cores showed disturbed sediment chronologies.

Temporal trends indicate a significant increase in sediment manganese levels within many of the Finger Lakes over the recent past. Sediment core profiles for manganese are shown in Figures 9.27 and 9.28. With the exception of Conesus Lake, peak manganese levels in each of the Finger Lakes sediment cores are found in the surficial sediment layer. This pattern is quite similar to the arsenic findings discussed above.

At the present time there are no established sediment quality assessment values for manganese in benthic sediments.

Figure 9.27: Manganese profiles in sediment cores from Skaneateles and Owasco Lakes.

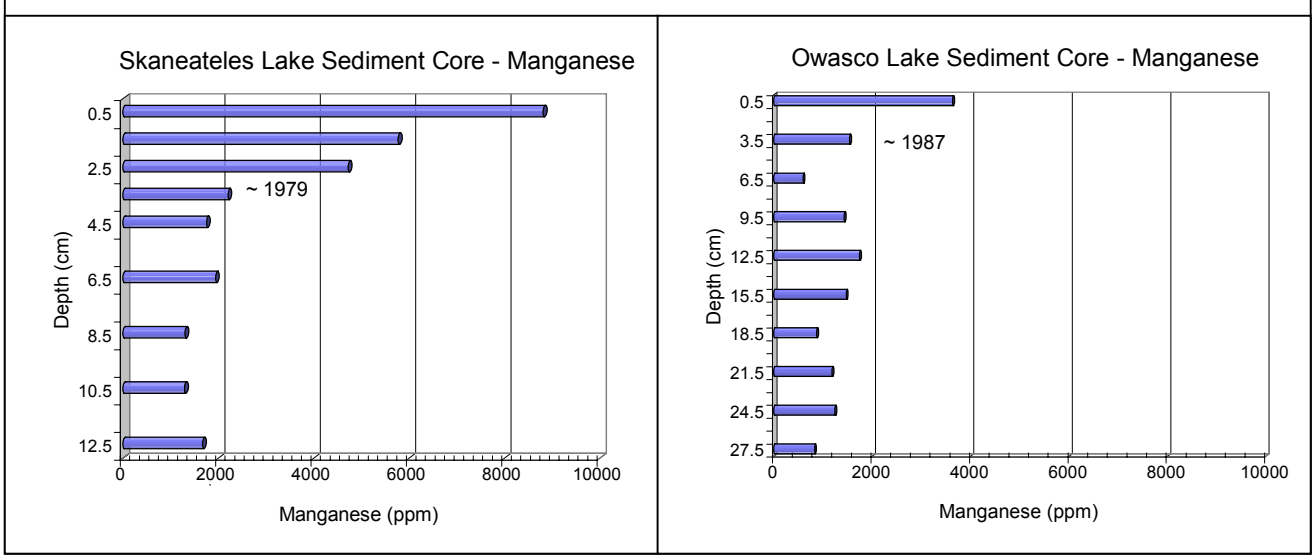
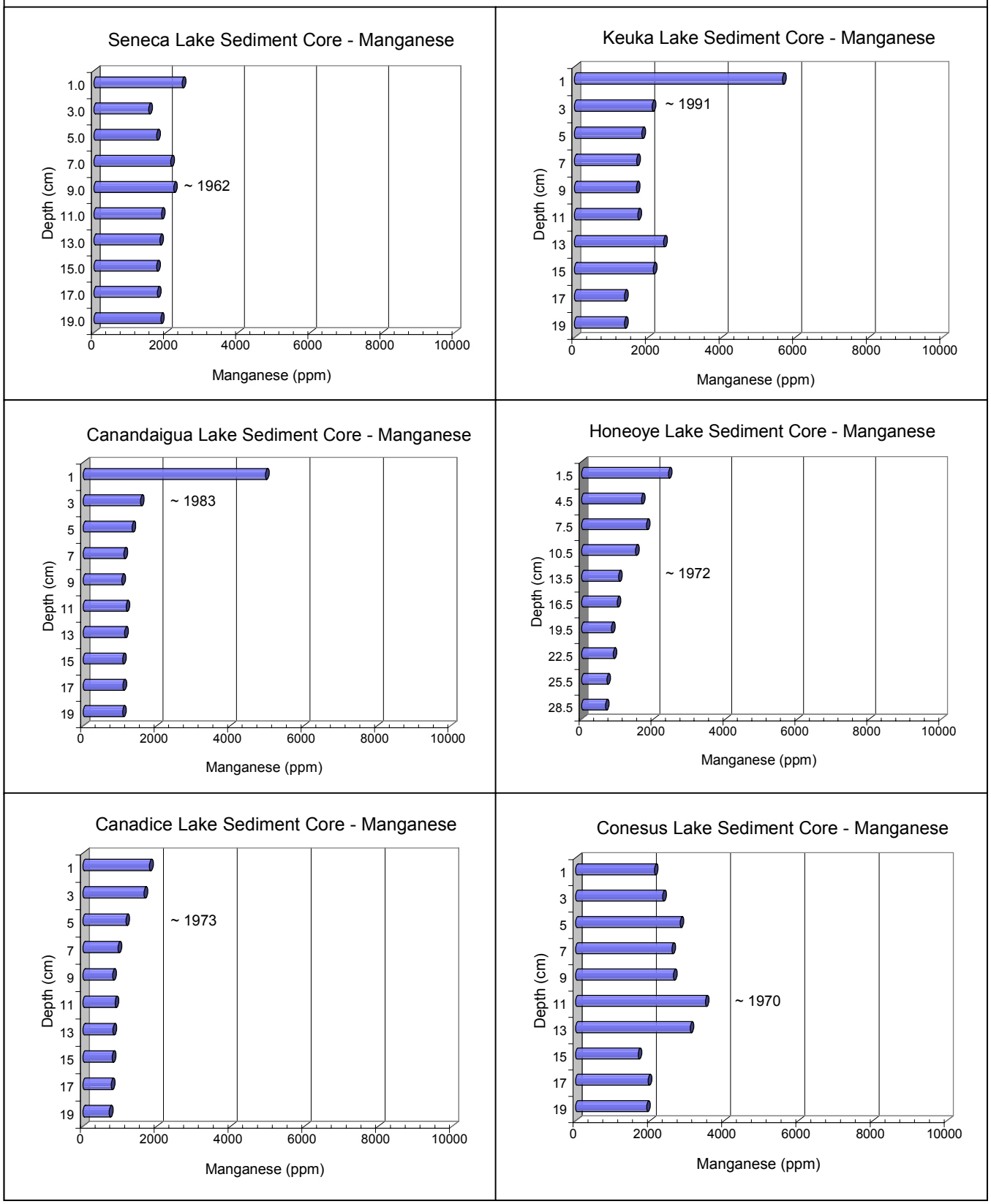


Figure 9.28: Manganese profiles in sediment cores for selected Finger Lakes



Mercury

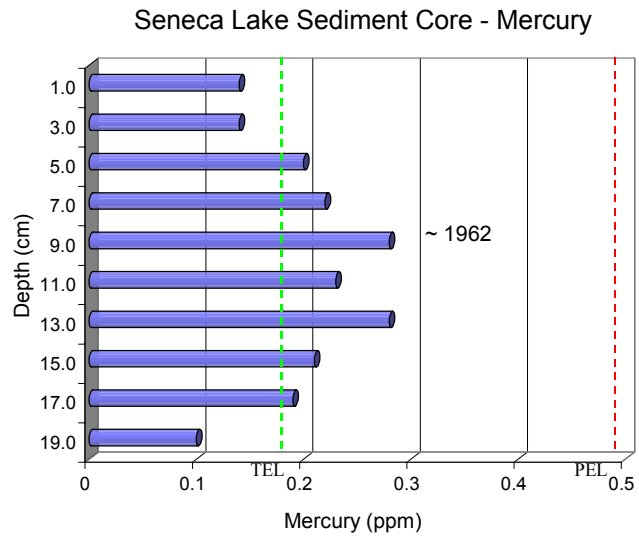
Mercury (Hg) is quite rare in the Earth's crust, and, although mercury can be released by natural processes, anthropogenic sources are the primary concern. Major human sources of mercury to the environment include the burning of fossil fuels and municipal waste incineration. The later route of release underscores the fact that a significant number of consumer products contain, or at one time contained, this metal. This list includes batteries, fluorescent lights, thermometers, and dental amalgams. While several of these products no longer contain mercury, the waste stream has a long "environmental memory".

As with the organochlorine compounds discussed above, concerns over mercury in the environment stem from: (a) its persistence within the environment – mercury tends to cycle rather efficiently through aquatic ecosystems; (b) the ability to bioaccumulate within aquatic food chains; and (c) its toxicity. Mercury is a neurotoxin that can adversely affect the central nervous system.

Unfortunately, results from this study are somewhat inconclusive with respect to mercury levels within the Finger Lakes due to the analytical detection limits of the laboratory methods used. In most instances, the analytical detection levels exceeded the TEL and/or PEL for mercury. Furthermore, analytical detection levels varied approximately 5 fold due to factors such as available sample mass and/or interferences. Thus, attempts to assess spatial variability in sediment mercury levels across the Finger Lakes is not possible with the data set available from this investigation.

With respect to temporal patterns of mercury contamination within the Finger Lakes, only one of the lake cores (Seneca Lake) showed sufficient levels of detection to establish a reasonable temporal profile for mercury (see Figure 9.29). Mercury levels observed within Seneca Lake sediments varied approximately 3 fold. Mercury levels peak at 0.28 mg/kg in approximately 1946 and 1962, and decline thereafter – although the final two sampling periods (1986 and 1994) may indicate that mercury levels have stabilized. The most recent mercury levels are somewhat elevated as compared to the oldest period available (ca. ~ 1922).

Figure 9.29: Seneca Lake sediment core mercury profile



Sediment quality assessment values for mercury are 0.174 and 0.49 for the TEL and PEL, respectively. Once again, analytical detection limits proved problematic when it came to evaluating sediment mercury levels in that the detection levels were frequently above the TEL and PEL. As can be seen from the Seneca Lake profile (Figure 9.29), the deeper sediments exceed the TEL, however, more recent sediments (including surficial sediments) are below the TEL and PEL.

Mercury levels within fish tissue (Lake trout) from the Finger Lakes are generally between 0.1 and 0.9 ppm. This is below the Food and Drug Administration's (FDA) actionable level of 1.0 ppm.

Nickel

Nickel (Ni) is found at relatively low levels within the earth's crust. Anthropogenic uses of nickel include the manufacture of stainless steel and other corrosion-resistant alloys, armor plates and vaults, and plating to provide a protective coating for other metals. Occupational exposure to nickel has been linked to increased risk of nasal and lung cancers. In addition, repeated exposures may lead to asthma and other respiratory ailments. The health and/or environmental effects of lower nickel exposure are not known.

Spatial comparisons of nickel levels within Finger Lakes sediments (Table 9.17) indicate a narrow range of concentrations. For example, in those lakes with intact sediment cores, peak nickel levels ranged from 46.1 ppm in Seneca Lake to 72 ppm within Skaneateles Lake. There was no apparent east-west trend in nickel levels, nor was there significant correlation with lake productivity levels. Once again, as with several other metals, nickel levels within the Cayuga Lake sediments appeared inordinately low – approximately half the level found in the other Finger Lakes. Nickel levels for Hemlock Lake are consistent with the other Finger Lakes.

Table 9.17: Nickel in Finger Lakes sediment cores

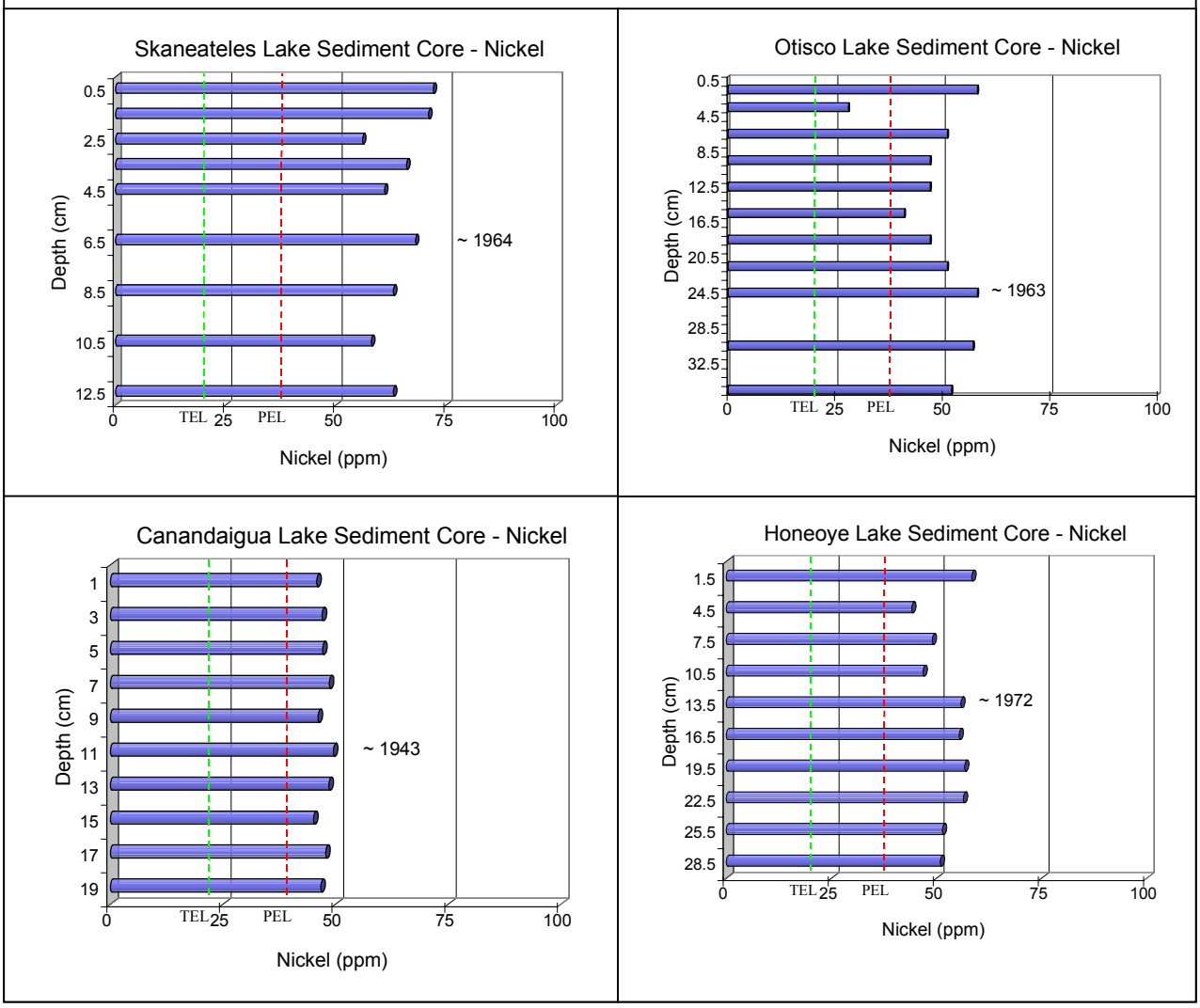
Lake	*Peak Ni (ppm)*	*Depth of Peak (cm)/~ Age*
Otisco	58	1-2 & 24-25 (1994 & 1963)
Skaneateles	72	0-1 (1994)
Owasco	66	12-13 (1965)
* Cayuga	29.9	na
Seneca	46.1	6-8 (1970)
Keuka	50.3	14-16 (1961)
Canandaigua	49.5	10-12 (1943)
Honeoye	58.4	0-3 (1996)
Canadice	53.4	2-4 (1983)
* Hemlock	57.6	na
Conesus	49.2	16-18 (1955)
TEL	18	-
PEL	36	-

* Cayuga Lake and Hemlock Lake cores showed disturbed sediment chronologies.

Temporal trends in sediment nickel levels vary somewhat within the Finger Lakes. For example, peak nickel levels occur between the early 1940s for Canandaigua Lake and the mid-1990s for Honeoye, Skaneateles, and Otisco Lakes. Sediment nickel profiles for several of the Finger Lakes cores are shown in Figure 9.30. While peak nickel levels within several of the lakes occur within surficial sediment layers, the levels do not vary greatly over time. For example, Skaneateles Lake sediments range from 56 – 72 mg/kg, while Honeoye Lake sediments range from 44.1 – 58.4 mg/kg.

The surficial sediments from all of the Finger Lakes cores, with the exception of Cayuga and Conesus Lakes, exceed both the TEL and PEL for nickel. Historical nickel levels (deep sediments) also consistently exceed these assessment values within each of the lakes. The uniform pattern observed for nickel levels, both spatially across lakes and temporally within given lakes, would suggest that nickel inputs are diffuse in nature and likely originating from either atmospheric transport or geological weathering. The environmental significance of the observed nickel levels in not clear.

Figure 9.30: Sediment nickel profiles from selected Finger Lakes



Zinc

Zinc (Zn) is found at relatively low levels within the earth's crust. Industrial uses of zinc include the manufacture of steel, dry cell batteries, pharmaceuticals, paint, rubber, dyes, wood preservatives, and the production of alloys (brass and bronze). Although zinc is an essential element in the human diet, ingestion or inhalation of elevated amounts of zinc can cause anemia and pancreatic damage.

Zinc levels within the Finger Lakes sediment cores were fairly uniform (see Table 9.18). For example, in those lakes for which intact sediment cores were available, peak zinc levels varied by approximately 40 percent. The lowest sediment zinc levels were observed in Keuka Lake, while the highest zinc levels observed are in Skaneateles Lake. The peak zinc level observed in Hemlock Lake sediments was 156 mg/kg, which is relatively consistent with the levels observed in most of the other Finger Lakes. However, as found with other metals, the peak zinc level observed within Cayuga Lake is unusually low.

Table 9.18: Zinc in Finger Lakes sediment cores

Lake	*Peak Zn (mg/kg)*	*Depth (cm)/~ Age*
Otisco	194	24-25 (1963)
Skaneateles	242	1-2 (1989)
Owasco	180	15-16 (1957)
* Cayuga	96.5	na
Seneca	176	6-8 (1970)
Keuka	168	14-16 (1961)
Canandaigua	173	6-8 (1963)
Honeoye	170	0-3 (1996)
Canadice	180	2-4 (1983)
* Hemlock	156	na
Conesus	195	12-14 (1965)
TEL	123	-
SEL	315	-

* Cayuga Lake and Hemlock Lake cores showed disturbed sediment chronologies.

Temporal trends for zinc within the Finger Lakes are inconsistent. For example, the trend within Conesus Lake is that of moderately declining zinc levels. On the other hand, the trend in Skaneateles Lake is toward moderately increasing levels of zinc. Vertical sediment profiles of zinc for these two lakes are presented in Figure 9.31.

Zinc levels within the sediments of nearly all of the Finger Lakes (Cayuga Lake being the only exception) are above the TEL, however, all were below the PEL. As discussed with nickel levels above, the findings would suggest that zinc inputs to the lake are diffuse in nature, and likely stem from either atmospheric transport and/or geological weathering.

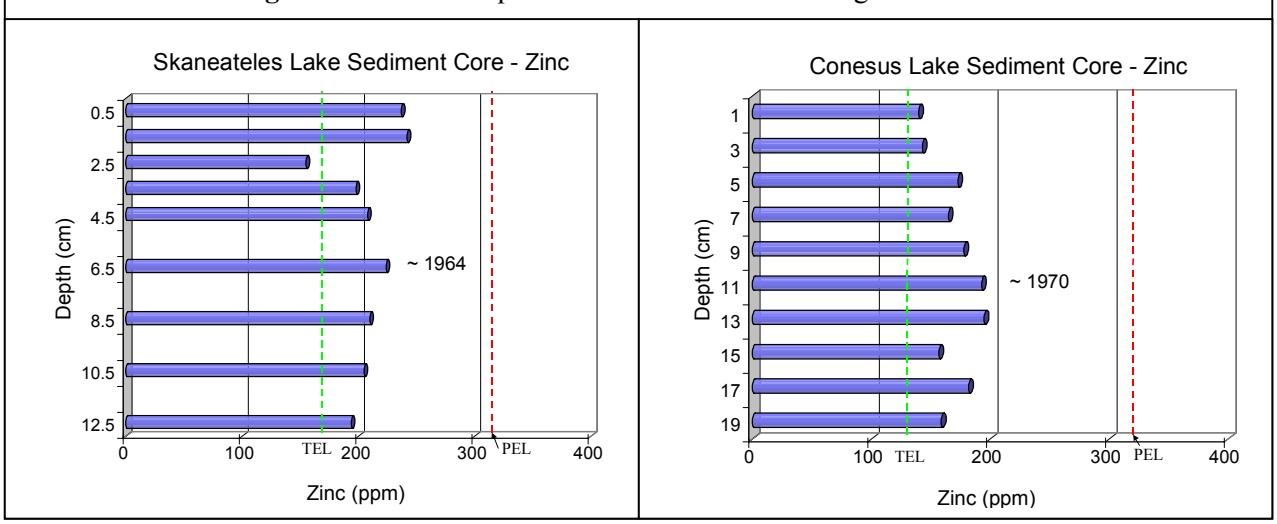



Figure 9.31: Vertical profiles of zinc in selected Finger Lakes cores